FIG.1

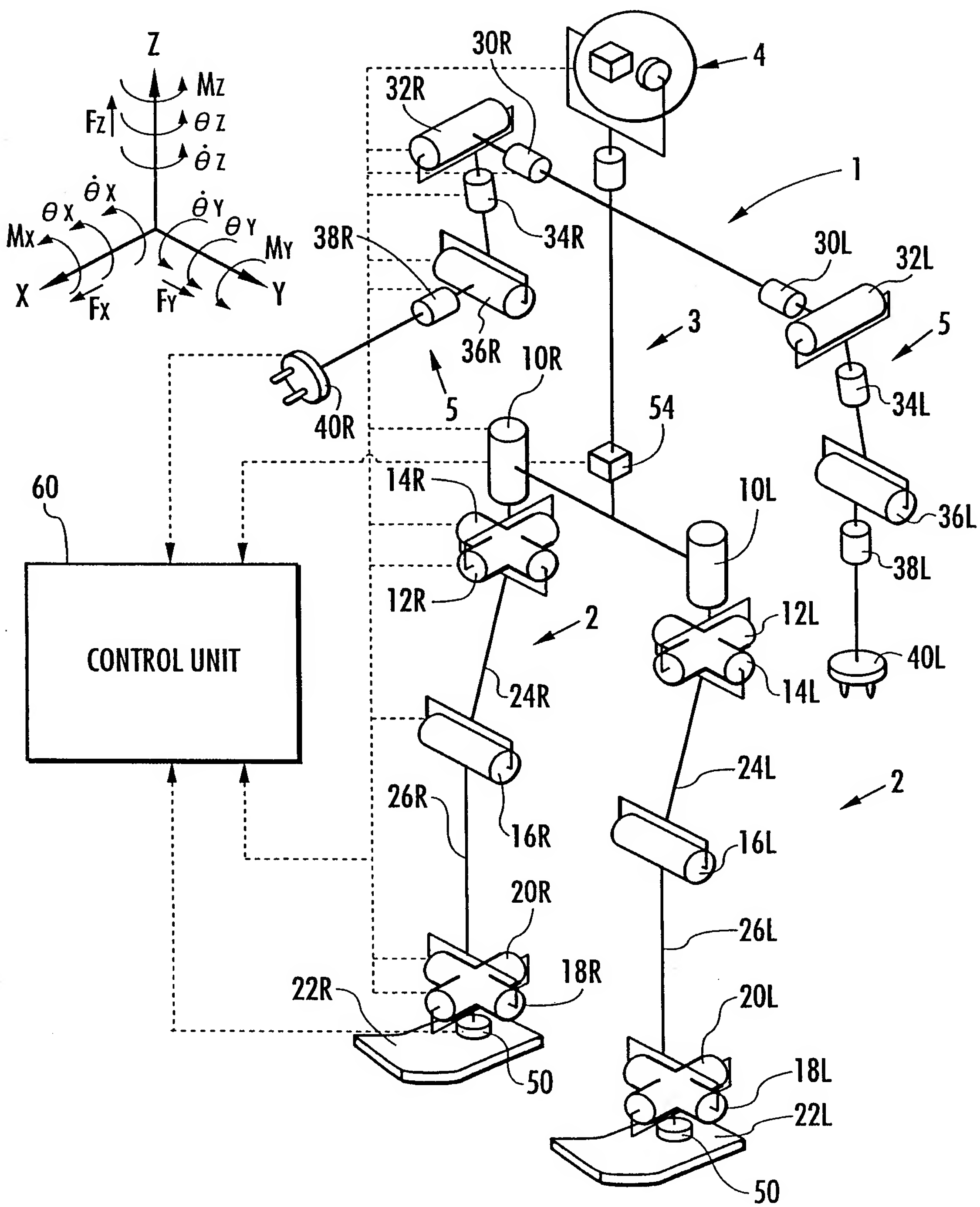

Z
Mz
Fz
θz
θ̇z
θ̇x
θx
Mx
X
Fx
Fy
θ̇y
θy
My
Y
30R
32R
4
1
34R
38R
30L
32L
36R
3
5
10R
5
40R
54
34L
60
14R
10L
36L
38L
12R
2
12L
CONTROL UNIT
14L
40L
24R
24L
2
26R
16R
16L
20R
26L
18R
22R
20L
18L
22L
50
50

FIG.2

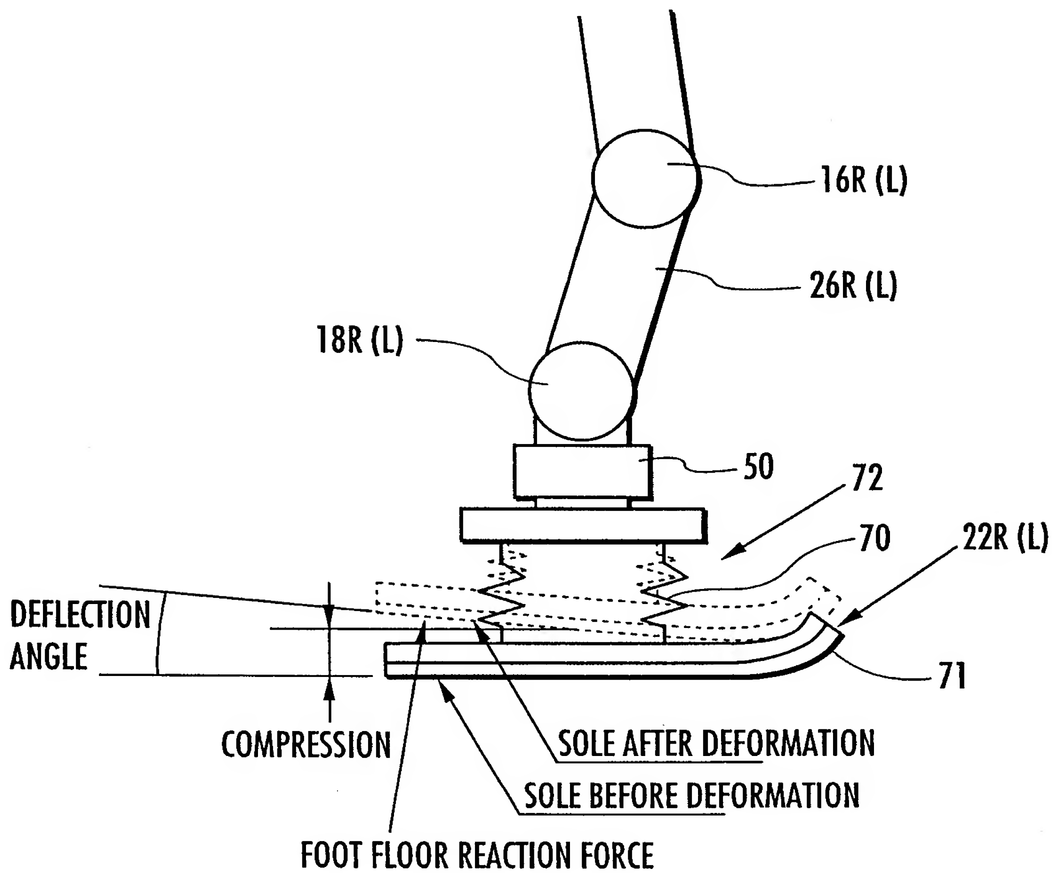

16R (L)
26R (L)
18R (L)
50
72
70
22R (L)
71
DEFLECTION ANGLE
COMPRESSION
SOLE AFTER DEFORMATION
SOLE BEFORE DEFORMATION
FOOT FLOOR REACTION FORCE

FIG.3

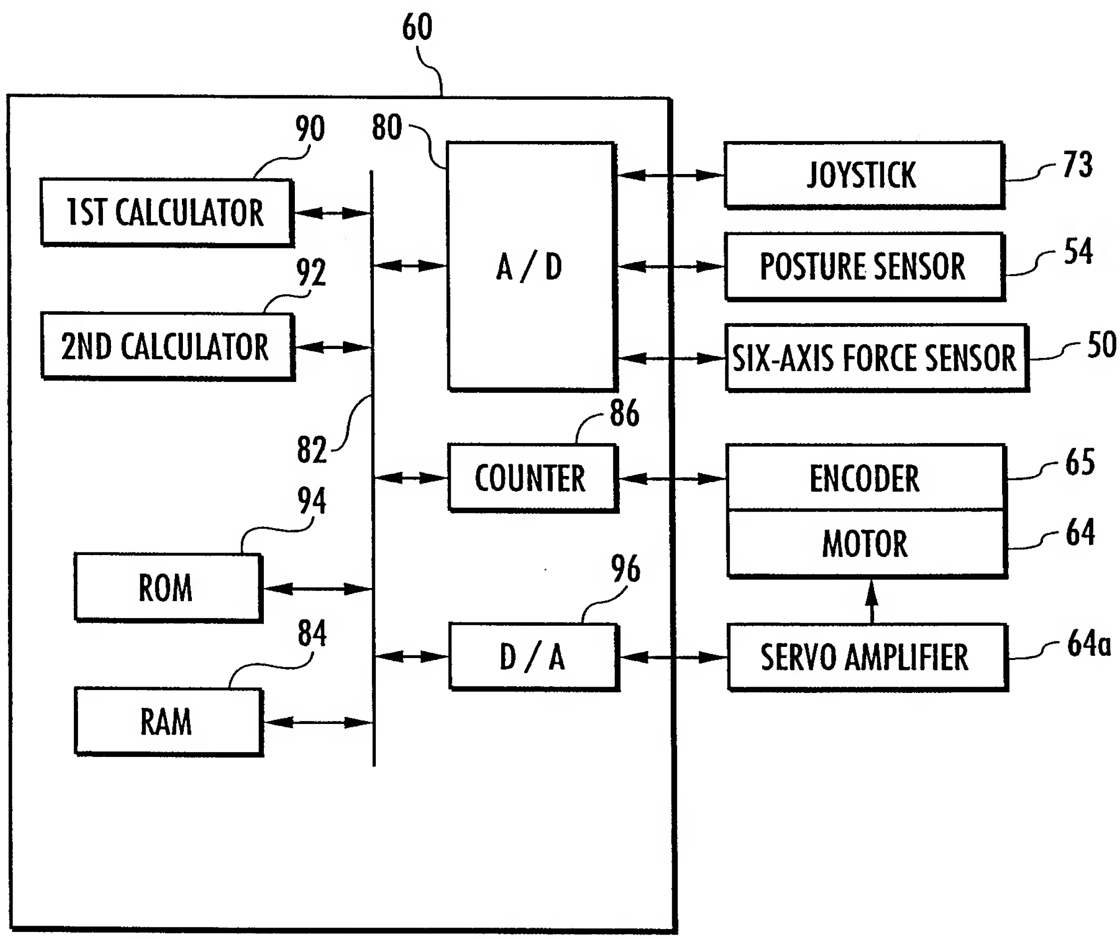

60
90
80
1ST CALCULATOR
92
2ND CALCULATOR
A / D
JOYSTICK
73
POSTURE SENSOR
54
SIX-AXIS FORCE SENSOR
50
82
86
COUNTER
ENCODER
65
MOTOR
64
94
ROM
96
84
D / A
SERVO AMPLIFIER
64a
RAM

FIG.4

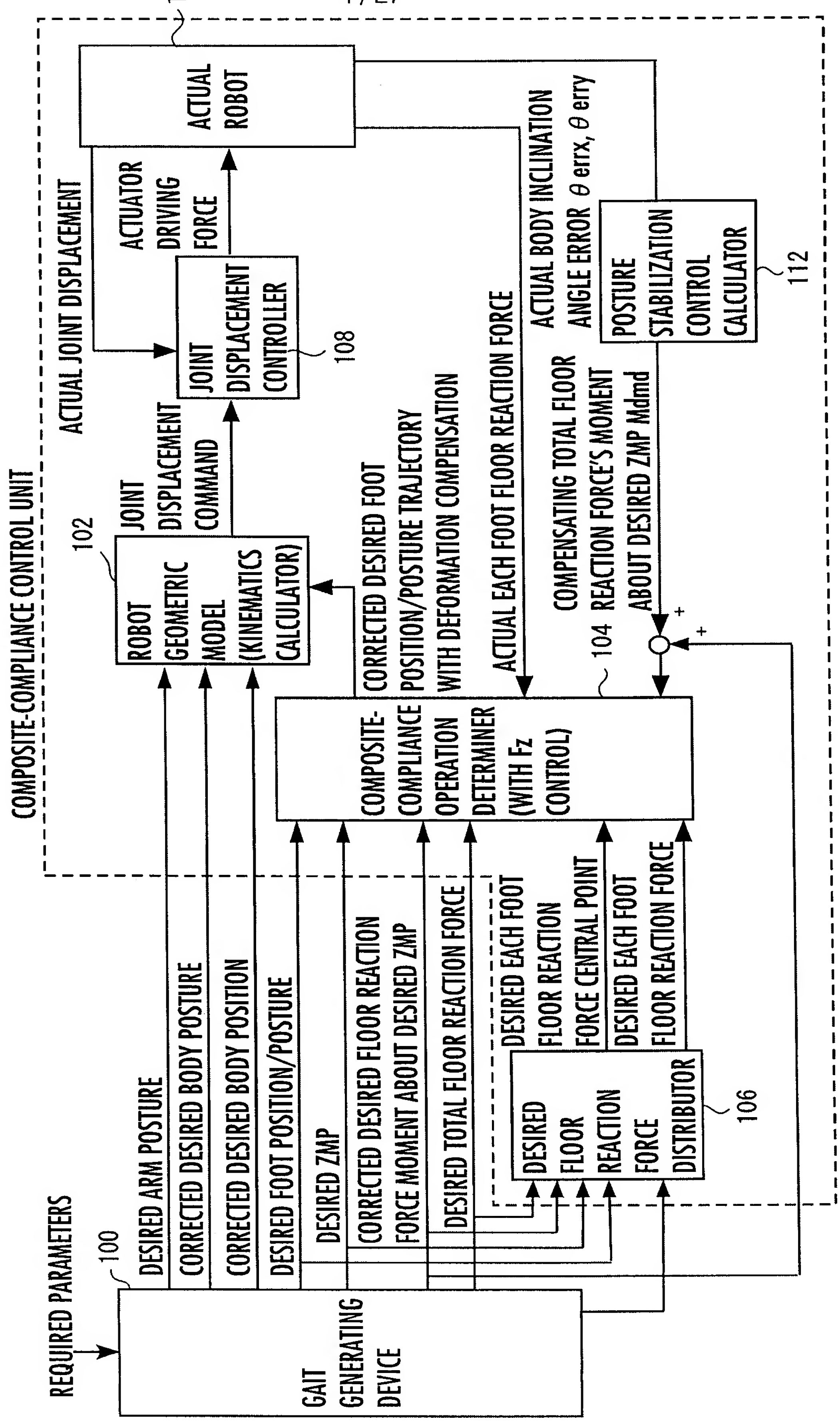

COMPOSITE-COMPLIANCE CONTROL UNIT
1
ACTUAL ROBOT
ACTUAL JOINT DISPLACEMENT
ACTUATOR DRIVING FORCE
JOINT DISPLACEMENT CONTROLLER
108
JOINT DISPLACEMENT COMMAND
ROBOT GEOMETRIC MODEL (KINEMATICS CALCULATOR)
102
CORRECTED DESIRED FOOT POSITION/POSTURE TRAJECTORY WITH DEFORMATION COMPENSATION
ACTUAL EACH FOOT FLOOR REACTION FORCE
ACTUAL BODY INCLINATION ANGLE ERROR θerrx, θerry
POSTURE STABILIZATION CONTROL CALCULATOR
112
COMPENSATING TOTAL FLOOR REACTION FORCE'S MOMENT ABOUT DESIRED ZMP Mdmd
+
+
104
COMPOSITE-COMPLIANCE OPERATION DETERMINER (WITH Fz CONTROL)
DESIRED EACH FOOT FLOOR REACTION FORCE CENTRAL POINT
DESIRED EACH FOOT FLOOR REACTION FORCE
DESIRED FLOOR REACTION FORCE DISTRIBUTOR
106
REQUIRED PARAMETERS
100
GAIT GENERATING DEVICE
DESIRED ARM POSTURE
CORRECTED DESIRED BODY POSTURE
CORRECTED DESIRED BODY POSITION
DESIRED FOOT POSITION/POSTURE
DESIRED ZMP
CORRECTED DESIRED FLOOR REACTION FORCE MOMENT ABOUT DESIRED ZMP
DESIRED TOTAL FLOOR REACTION FORCE

FIG.5

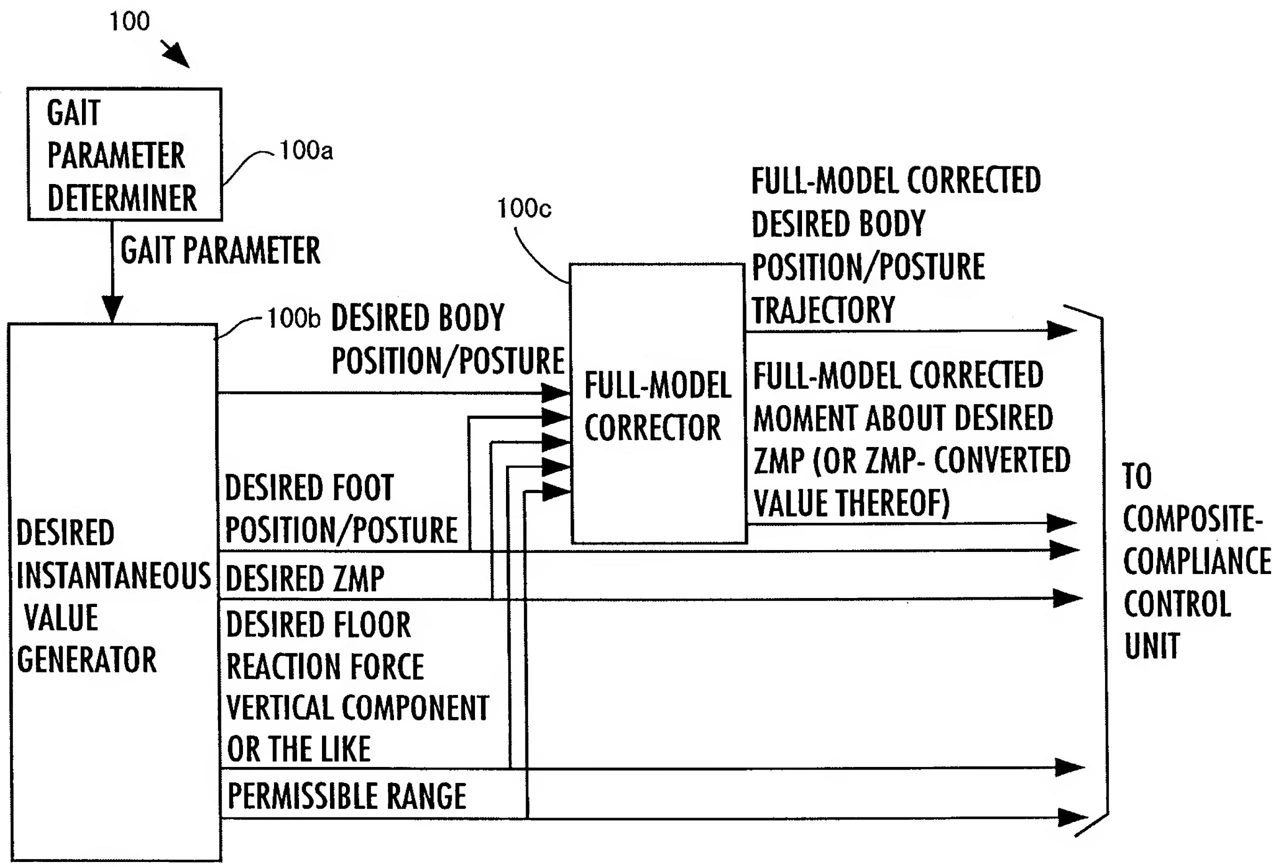

100
GAIT PARAMETER DETERMINER
100a
GAIT PARAMETER
100b
DESIRED BODY POSITION/POSTURE
100c
FULL-MODEL CORRECTOR
FULL-MODEL CORRECTED DESIRED BODY POSITION/POSTURE TRAJECTORY
FULL-MODEL CORRECTED MOMENT ABOUT DESIRED ZMP (OR ZMP- CONVERTED VALUE THEREOF)
DESIRED INSTANTANEOUS VALUE GENERATOR
DESIRED FOOT POSITION/POSTURE
DESIRED ZMP
DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT OR THE LIKE
PERMISSIBLE RANGE
TO COMPOSITE-COMPLIANCE CONTROL UNIT

FIG.6(a)

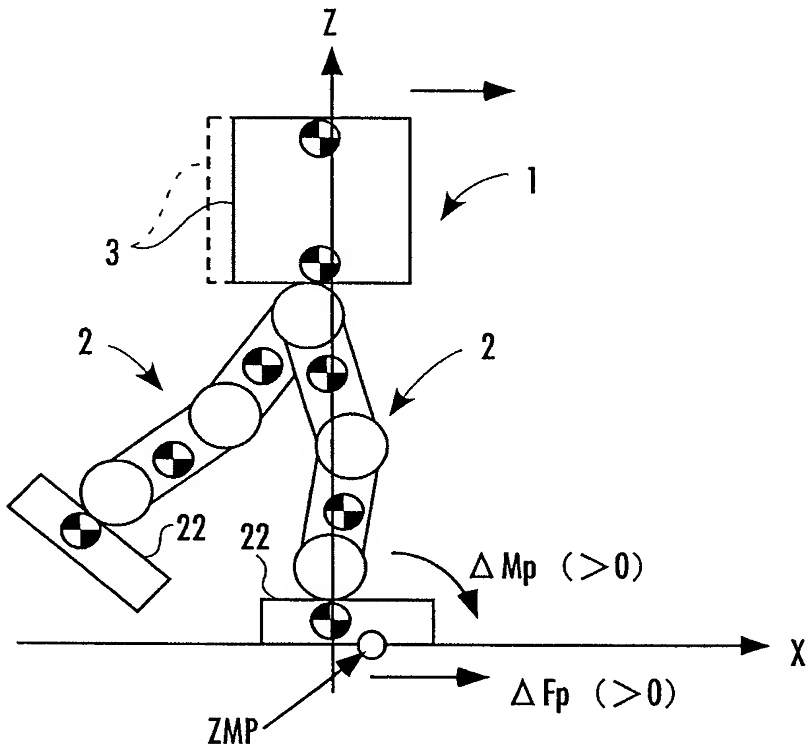

Z
1
3
2
2
22
22
Δ Mp (>0)
X
ZMP
Δ Fp (>0)

FIG.6(b)

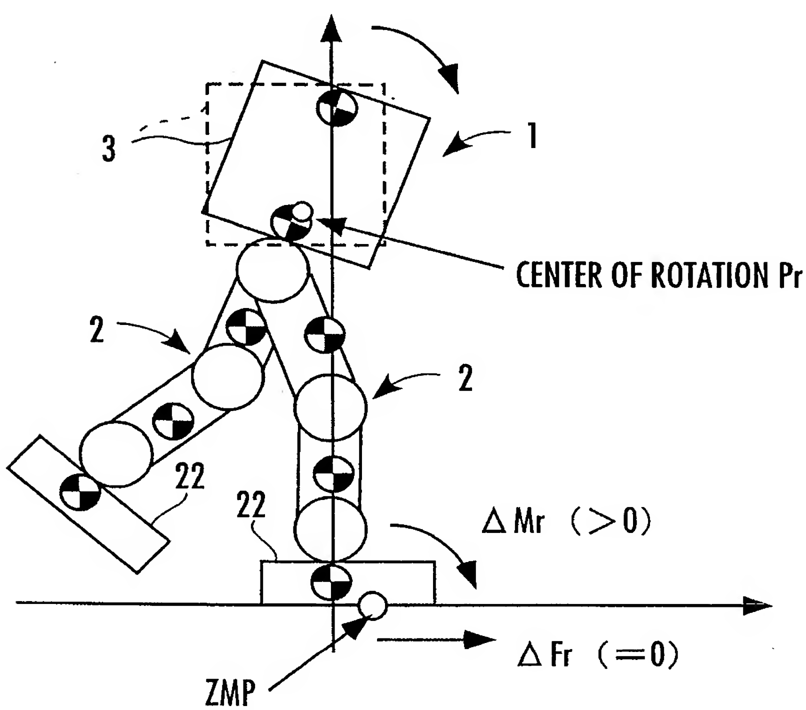

1
3
CENTER OF ROTATION Pr
2
2
22
22
Δ Mr (>0)
ZMP
Δ Fr (=0)

FIG. 7

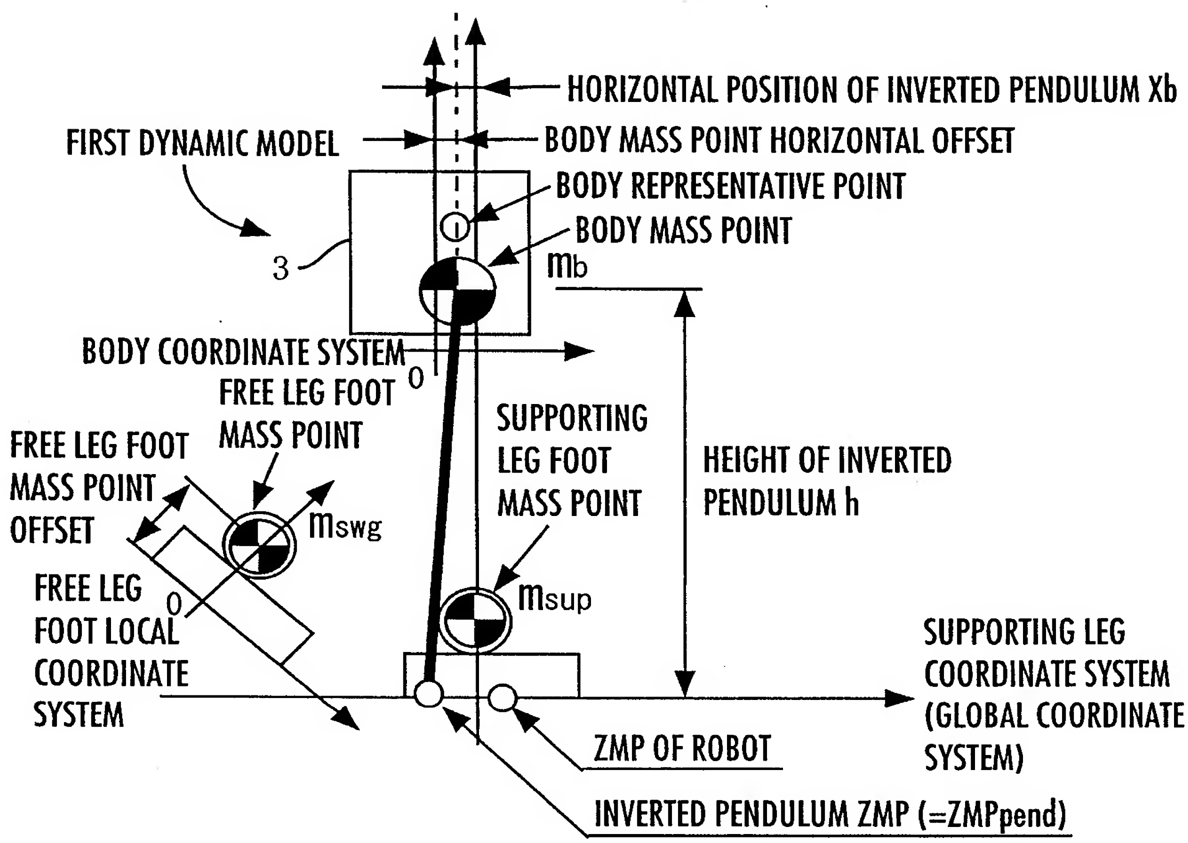

HORIZONTAL POSITION OF INVERTED PENDULUM Xb
FIRST DYNAMIC MODEL
BODY MASS POINT HORIZONTAL OFFSET
BODY REPRESENTATIVE POINT
BODY MASS POINT
3
mb
BODY COORDINATE SYSTEM
0
FREE LEG FOOT MASS POINT
FREE LEG FOOT MASS POINT OFFSET
mswg
SUPPORTING LEG FOOT MASS POINT
HEIGHT OF INVERTED PENDULUM h
FREE LEG FOOT LOCAL COORDINATE SYSTEM
0
msup
SUPPORTING LEG COORDINATE SYSTEM (GLOBAL COORDINATE SYSTEM)
ZMP OF ROBOT
INVERTED PENDULUM ZMP (=ZMPpend)

FIG. 8

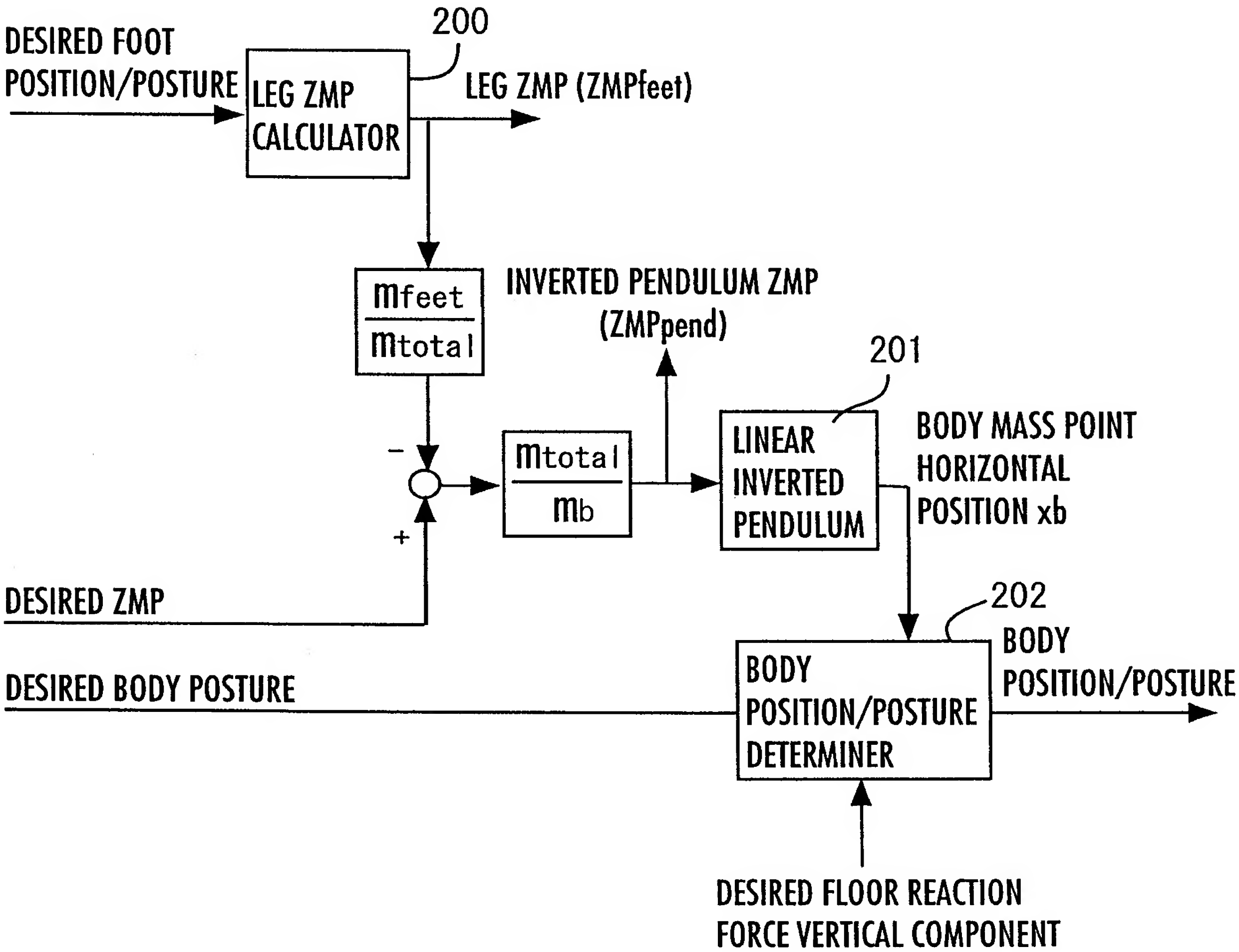

DESIRED FOOT POSITION/POSTURE
200
LEG ZMP CALCULATOR
LEG ZMP (ZMPfeet)
mfeet / mtotal
INVERTED PENDULUM ZMP (ZMPpend)
201
−
+
mtotal / mb
LINEAR INVERTED PENDULUM
BODY MASS POINT HORIZONTAL POSITION xb
DESIRED ZMP
202
BODY POSITION/POSTURE
DESIRED BODY POSTURE
BODY POSITION/POSTURE DETERMINER
DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT

FIG.9

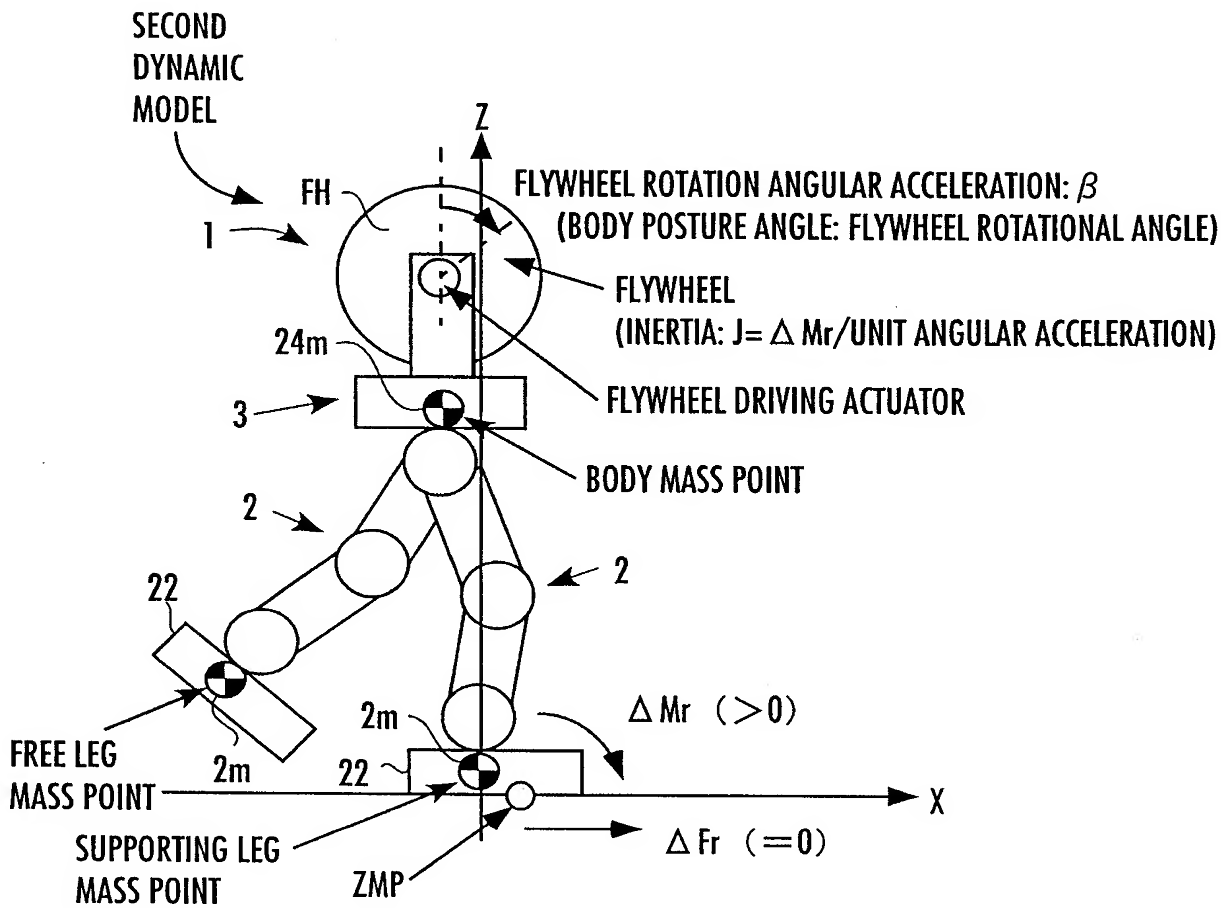

SECOND DYNAMIC MODEL
Z
FH
1
FLYWHEEL ROTATION ANGULAR ACCELERATION: β
(BODY POSTURE ANGLE: FLYWHEEL ROTATIONAL ANGLE)
FLYWHEEL
(INERTIA: J= Δ Mr/UNIT ANGULAR ACCELERATION)
24m
3
FLYWHEEL DRIVING ACTUATOR
BODY MASS POINT
2
2
22
2m
Δ Mr (>0)
FREE LEG MASS POINT
2m
22
X
SUPPORTING LEG MASS POINT
ZMP
Δ Fr (=0)

FIG.10

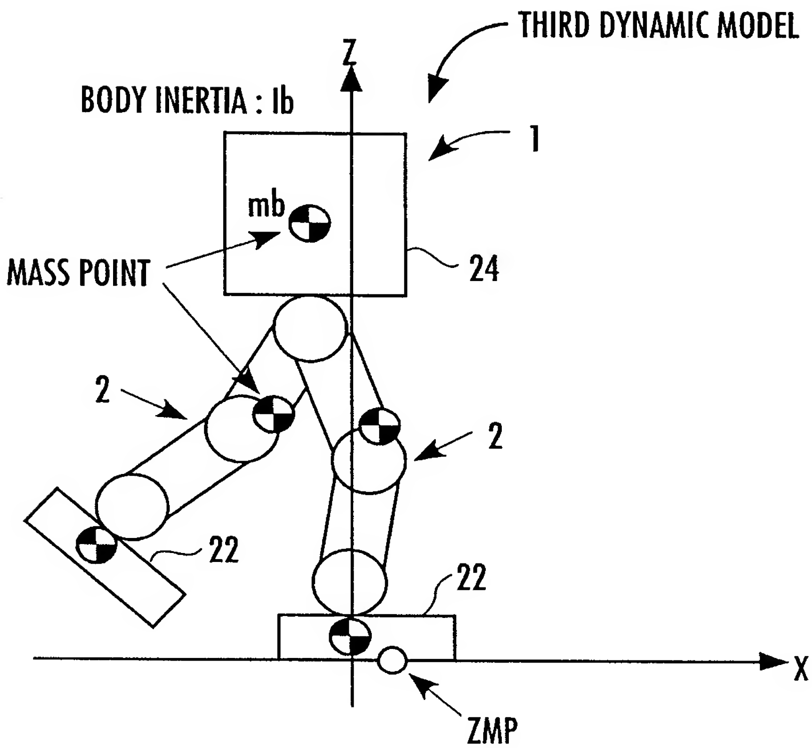

THIRD DYNAMIC MODEL
Z
BODY INERTIA : Ib
1
mb
MASS POINT
24
2
2
22
22
X
ZMP

FIG.11

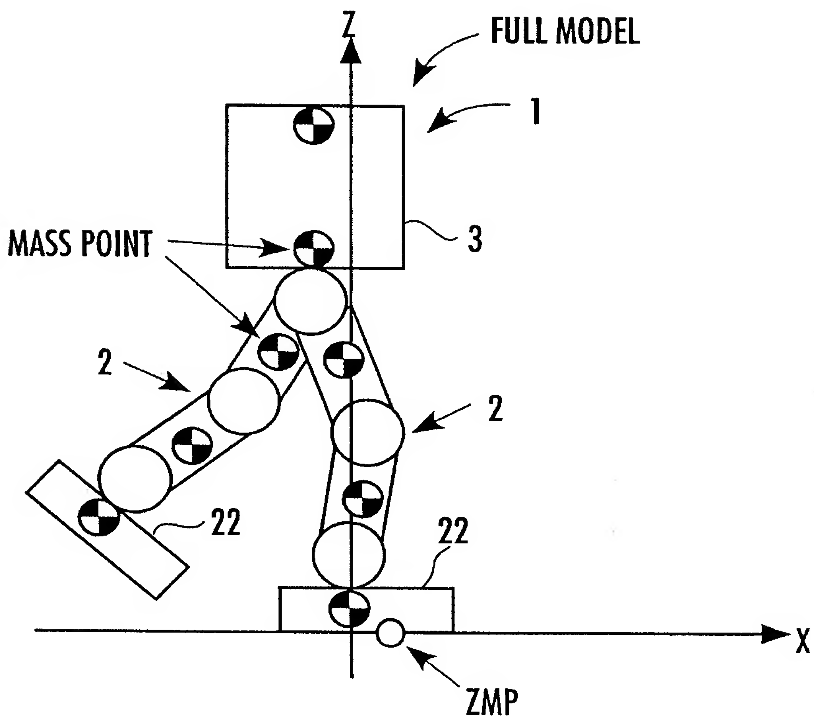


FIG.12

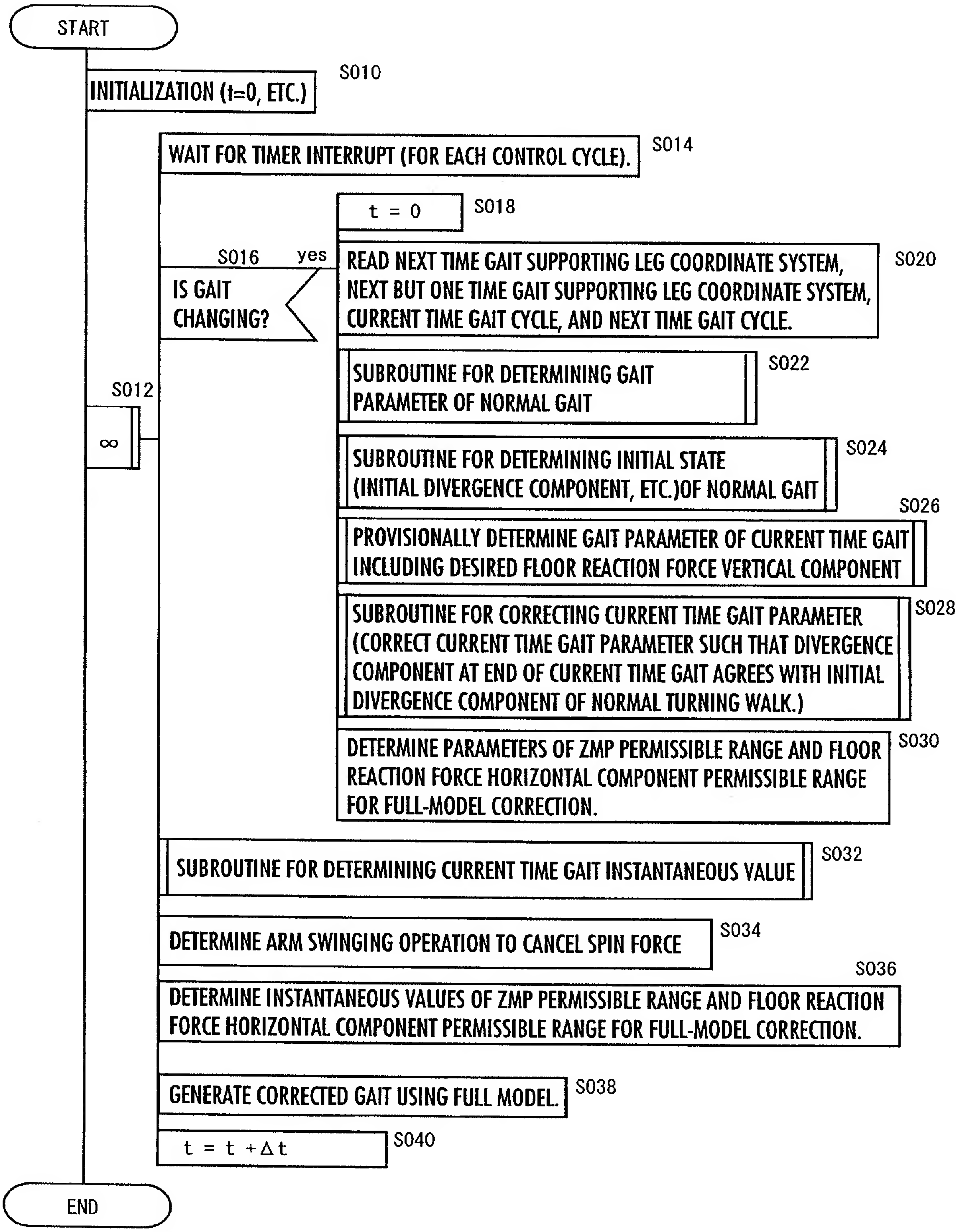

START
INITIALIZATION (t=0, ETC.)
S010
WAIT FOR TIMER INTERRUPT (FOR EACH CONTROL CYCLE).
S014
t = 0
S018
S016
yes
IS GAIT CHANGING?
READ NEXT TIME GAIT SUPPORTING LEG COORDINATE SYSTEM, NEXT BUT ONE TIME GAIT SUPPORTING LEG COORDINATE SYSTEM, CURRENT TIME GAIT CYCLE, AND NEXT TIME GAIT CYCLE.
S020
SUBROUTINE FOR DETERMINING GAIT PARAMETER OF NORMAL GAIT
S022
S012
∞
SUBROUTINE FOR DETERMINING INITIAL STATE (INITIAL DIVERGENCE COMPONENT, ETC.)OF NORMAL GAIT
S024
S026
PROVISIONALLY DETERMINE GAIT PARAMETER OF CURRENT TIME GAIT INCLUDING DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT
SUBROUTINE FOR CORRECTING CURRENT TIME GAIT PARAMETER (CORRECT CURRENT TIME GAIT PARAMETER SUCH THAT DIVERGENCE COMPONENT AT END OF CURRENT TIME GAIT AGREES WITH INITIAL DIVERGENCE COMPONENT OF NORMAL TURNING WALK.)
S028
DETERMINE PARAMETERS OF ZMP PERMISSIBLE RANGE AND FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE FOR FULL-MODEL CORRECTION.
S030
SUBROUTINE FOR DETERMINING CURRENT TIME GAIT INSTANTANEOUS VALUE
S032
DETERMINE ARM SWINGING OPERATION TO CANCEL SPIN FORCE
S034
S036
DETERMINE INSTANTANEOUS VALUES OF ZMP PERMISSIBLE RANGE AND FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE FOR FULL-MODEL CORRECTION.
GENERATE CORRECTED GAIT USING FULL MODEL.
S038
t = t +Δt
S040
END

FIG.13

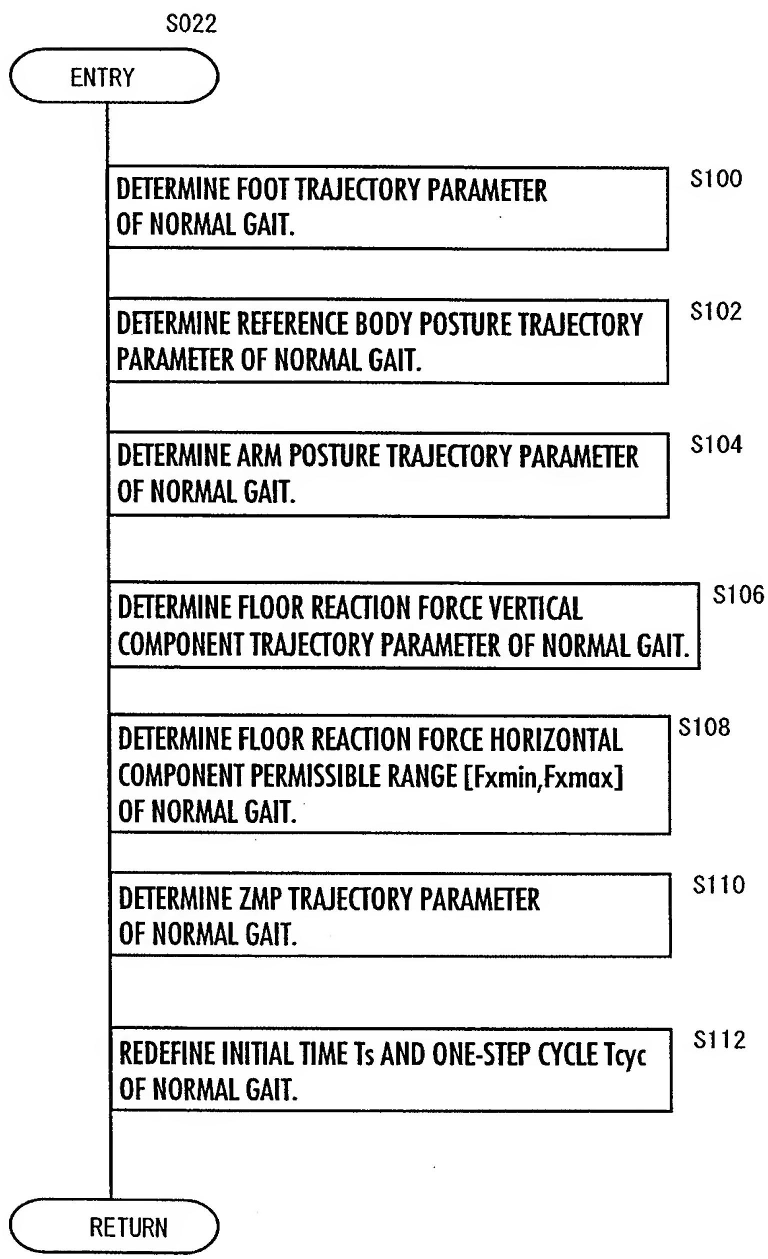
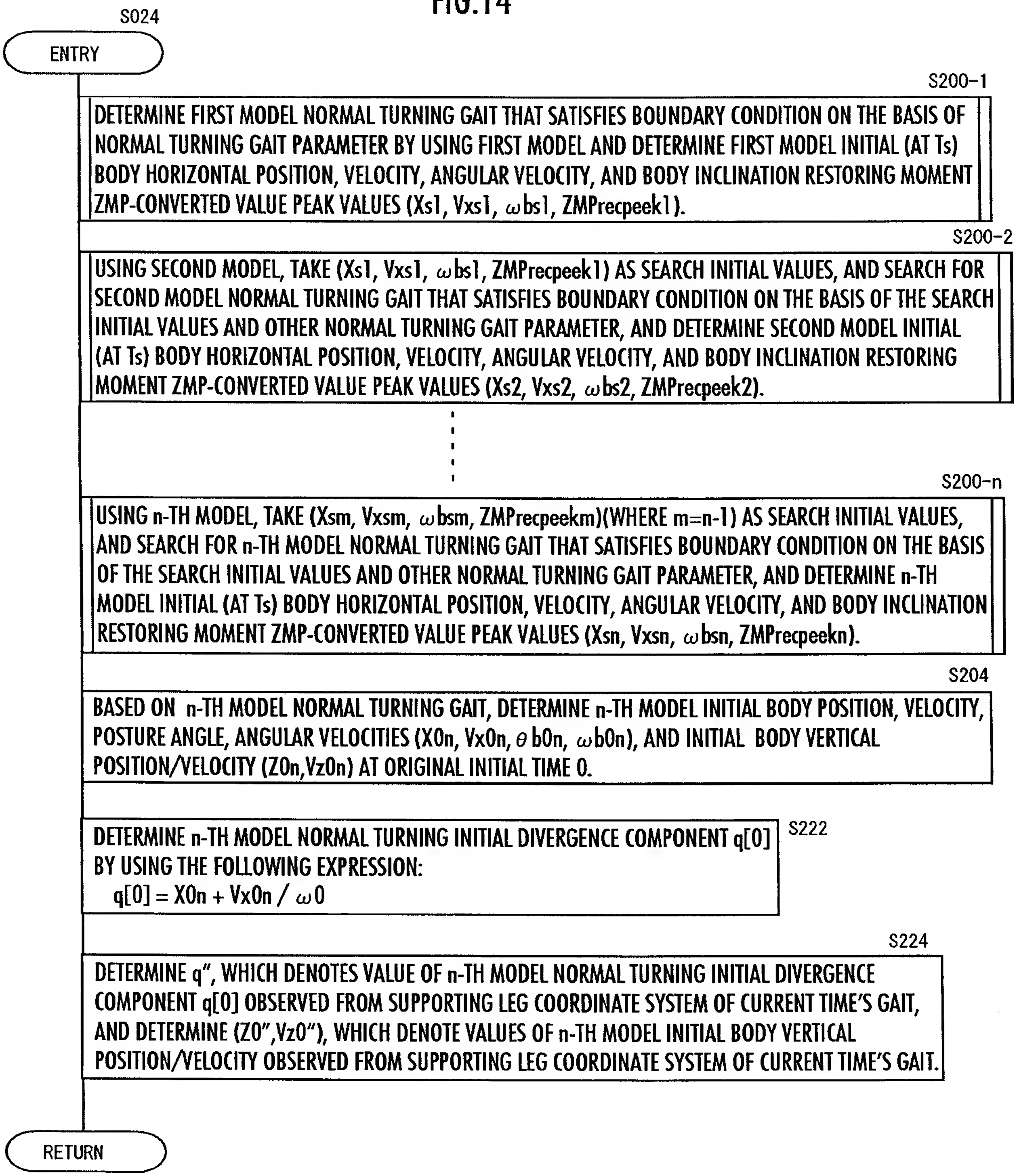

S022
ENTRY
DETERMINE FOOT TRAJECTORY PARAMETER OF NORMAL GAIT.
S100
DETERMINE REFERENCE BODY POSTURE TRAJECTORY PARAMETER OF NORMAL GAIT.
S102
DETERMINE ARM POSTURE TRAJECTORY PARAMETER OF NORMAL GAIT.
S104
DETERMINE FLOOR REACTION FORCE VERTICAL COMPONENT TRAJECTORY PARAMETER OF NORMAL GAIT.
S106
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE [Fxmin,Fxmax] OF NORMAL GAIT.
S108
DETERMINE ZMP TRAJECTORY PARAMETER OF NORMAL GAIT.
S110
REDEFINE INITIAL TIME Ts AND ONE-STEP CYCLE Tcyc OF NORMAL GAIT.
S112
RETURN

FIG.14


S024
ENTRY
S200-1
DETERMINE FIRST MODEL NORMAL TURNING GAIT THAT SATISFIES BOUNDARY CONDITION ON THE BASIS OF NORMAL TURNING GAIT PARAMETER BY USING FIRST MODEL AND DETERMINE FIRST MODEL INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUES (Xs1, Vxs1, ωbs1, ZMPrecpeek1).
S200-2
USING SECOND MODEL, TAKE (Xs1, Vxs1, ωbs1, ZMPrecpeek1) AS SEARCH INITIAL VALUES, AND SEARCH FOR SECOND MODEL NORMAL TURNING GAIT THAT SATISFIES BOUNDARY CONDITION ON THE BASIS OF THE SEARCH INITIAL VALUES AND OTHER NORMAL TURNING GAIT PARAMETER, AND DETERMINE SECOND MODEL INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUES (Xs2, Vxs2, ωbs2, ZMPrecpeek2).
S200-n
USING n-TH MODEL, TAKE (Xsm, Vxsm, ωbsm, ZMPrecpeekm)(WHERE m=n-1) AS SEARCH INITIAL VALUES, AND SEARCH FOR n-TH MODEL NORMAL TURNING GAIT THAT SATISFIES BOUNDARY CONDITION ON THE BASIS OF THE SEARCH INITIAL VALUES AND OTHER NORMAL TURNING GAIT PARAMETER, AND DETERMINE n-TH MODEL INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUES (Xsn, Vxsn, ωbsn, ZMPrecpeekn).
S204
BASED ON n-TH MODEL NORMAL TURNING GAIT, DETERMINE n-TH MODEL INITIAL BODY POSITION, VELOCITY, POSTURE ANGLE, ANGULAR VELOCITIES (X0n, Vx0n, θb0n, ωb0n), AND INITIAL BODY VERTICAL POSITION/VELOCITY (Z0n,Vz0n) AT ORIGINAL INITIAL TIME 0.
S222
DETERMINE n-TH MODEL NORMAL TURNING INITIAL DIVERGENCE COMPONENT q[0] BY USING THE FOLLOWING EXPRESSION:
q[0] = X0n + Vx0n / ω0
S224
DETERMINE q", WHICH DENOTES VALUE OF n-TH MODEL NORMAL TURNING INITIAL DIVERGENCE COMPONENT q[0] OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF CURRENT TIME'S GAIT, AND DETERMINE (Z0",Vz0"), WHICH DENOTE VALUES OF n-TH MODEL INITIAL BODY VERTICAL POSITION/VELOCITY OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF CURRENT TIME'S GAIT.
RETURN

# FIG.15

S200-1 ENTRY

S250 DETERMINE INITIAL STATES (STATES AT INITIAL TIME Ts) OF FOOT POSITION/POSTURE, BODY POSTURE ANGLE $\theta$bs, AND ARM POSTURE ON THE BASIS OF NORMAL TURNING GAIT PARAMETER

S252 PROVISIONALLY DETERMINE FIRST MODEL INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATES (Xs1, Vxs1, $\omega$bs1, ZMPrecpeek1).

S254 ∞

S256 DETERMINE FIRST MODEL INITIAL BODY VERTICAL POSITION/VELOCITY (Zs1, Vzs1).

S258 USING FIRST DYNAMIC MODEL, GENERATE FIRST MODEL GAIT ON THE BASIS OF NORMAL TURNING GAIT PARAMETER INCLUDING ZMPrecpeek1, TAKING $\theta$bs1,(Xs1, Vxs1, $\omega$bs1), (Zs1,Vzs1) AS INITIAL STATES OF BODY.

S260 CONVERT BODY HORIZONTAL POSITION, VELOCITY, POSTURE ANGLE, AND ANGULAR VELOCITY AT TERMINATING END OF GENERATED GAIT INTO VALUES OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF NEXT STEP, AND DENOTE THE CONVERTED VALUES AS (Xe1, Vxe1, $\theta$be1, $\omega$be1).

S262 BOUNDARY CONDITION ERRORS (errx, errv, err$\theta$, err$\omega$)
= (Xs1, Vxs1, $\theta$bs1, $\omega$bs1)-(Xe1, Vxe1, $\theta$be1, $\omega$be1)

S264 ARE ALL errx, errv, err$\theta$b, AND err$\omega$b WITHIN PERMISSIBLE RANGES?

yes → LEAVE REPETITION LOOP.

S266 DETERMINE A PLURALITY OF CANDIDATES (Xs1+$\Delta$Xs, Vxs1, $\omega$bs1, ZMPrecpeek1), (Xs1, Vxs1+$\Delta$Vxs, $\omega$bs1, ZMPrecpeek1), (Xs1, Vxs1, $\omega$bs1+$\Delta\omega$bs, ZMPrecpeek1), (Xs1, Vxs1, $\omega$bs1, ZMPrecpeek1+$\Delta$ZMPrecpeek) IN THE VICINITY OF (Xs1, Vxs1, $\omega$bs1, ZMPrecpeek1), AND BASED ON THEM, DETERMINE BOUNDARY CONDITION ERROR CORRESPONDING TO EACH OF THEM AS DESCRIBED ABOVE.

S268 DETERMINE NEW CANDIDATES (Xs1, Vxs1, $\omega$bs1, ZMPrecpeek1) ON THE BASIS OF BOUNDARY CONDITION ERRORS CORRESPONDING TO (Xs1, Vxs1, $\omega$bs1, ZMPrecpeek1) AND EACH OF CANDIDATES IN THE VICINITY THEREOF.

RETURN

FIG.16

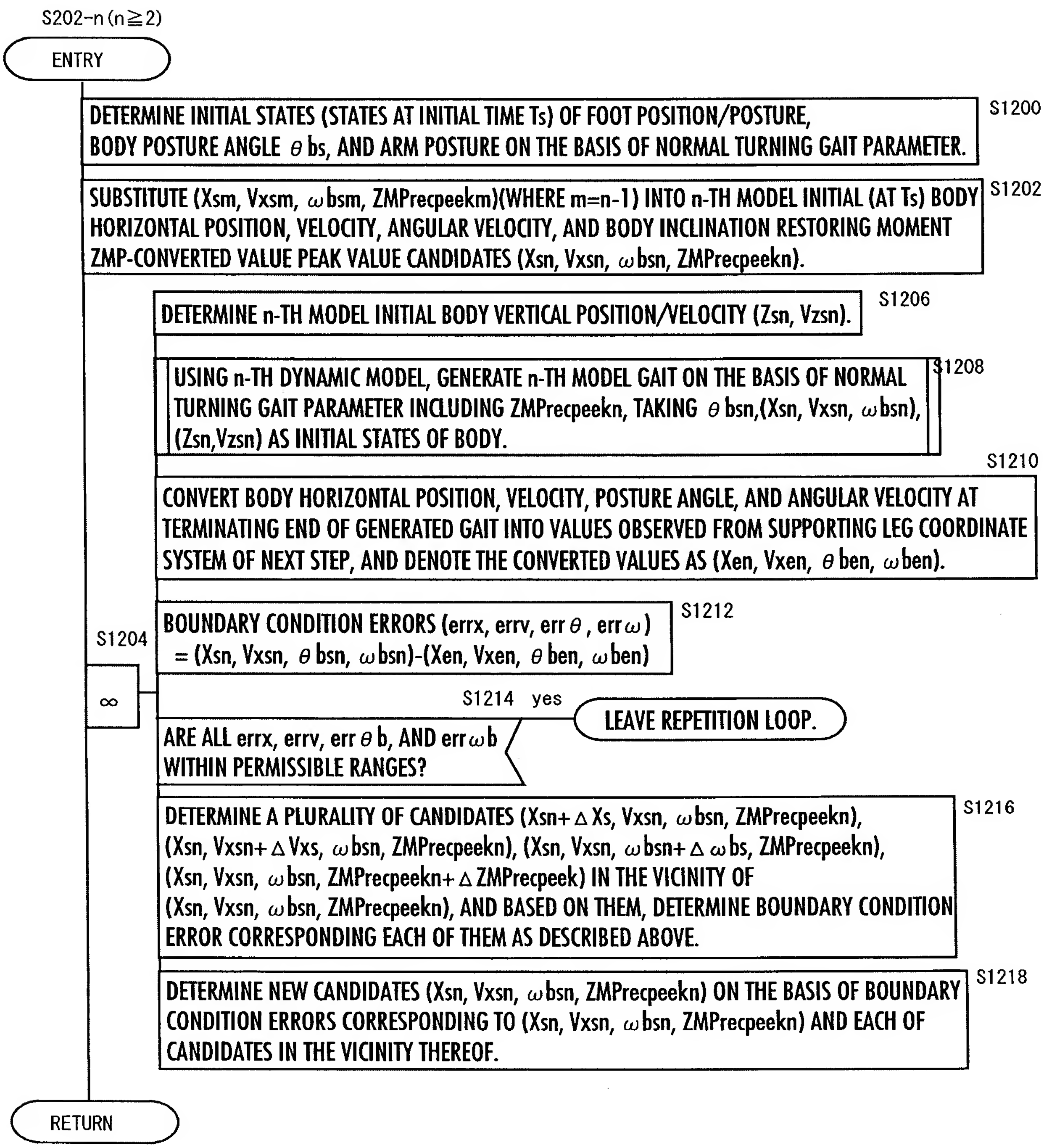

S202-n (n≧2)
ENTRY
DETERMINE INITIAL STATES (STATES AT INITIAL TIME Ts) OF FOOT POSITION/POSTURE, BODY POSTURE ANGLE θbs, AND ARM POSTURE ON THE BASIS OF NORMAL TURNING GAIT PARAMETER.
S1200
SUBSTITUTE (Xsm, Vxsm, ωbsm, ZMPrecpeekm)(WHERE m=n-1) INTO n-TH MODEL INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATES (Xsn, Vxsn, ωbsn, ZMPrecpeekn).
S1202
DETERMINE n-TH MODEL INITIAL BODY VERTICAL POSITION/VELOCITY (Zsn, Vzsn).
S1206
USING n-TH DYNAMIC MODEL, GENERATE n-TH MODEL GAIT ON THE BASIS OF NORMAL TURNING GAIT PARAMETER INCLUDING ZMPrecpeekn, TAKING θbsn,(Xsn, Vxsn, ωbsn), (Zsn,Vzsn) AS INITIAL STATES OF BODY.
S1208
S1210
CONVERT BODY HORIZONTAL POSITION, VELOCITY, POSTURE ANGLE, AND ANGULAR VELOCITY AT TERMINATING END OF GENERATED GAIT INTO VALUES OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF NEXT STEP, AND DENOTE THE CONVERTED VALUES AS (Xen, Vxen, θben, ωben).
S1204
∞
BOUNDARY CONDITION ERRORS (errx, errv, errθ, errω)
= (Xsn, Vxsn, θbsn, ωbsn)-(Xen, Vxen, θben, ωben)
S1212
S1214
yes
LEAVE REPETITION LOOP.
ARE ALL errx, errv, errθb, AND errωb WITHIN PERMISSIBLE RANGES?
DETERMINE A PLURALITY OF CANDIDATES (Xsn+ΔXs, Vxsn, ωbsn, ZMPrecpeekn), (Xsn, Vxsn+ΔVxs, ωbsn, ZMPrecpeekn), (Xsn, Vxsn, ωbsn+Δωbs, ZMPrecpeekn), (Xsn, Vxsn, ωbsn, ZMPrecpeekn+ΔZMPrecpeek) IN THE VICINITY OF (Xsn, Vxsn, ωbsn, ZMPrecpeekn), AND BASED ON THEM, DETERMINE BOUNDARY CONDITION ERROR CORRESPONDING EACH OF THEM AS DESCRIBED ABOVE.
S1216
DETERMINE NEW CANDIDATES (Xsn, Vxsn, ωbsn, ZMPrecpeekn) ON THE BASIS OF BOUNDARY CONDITION ERRORS CORRESPONDING TO (Xsn, Vxsn, ωbsn, ZMPrecpeekn) AND EACH OF CANDIDATES IN THE VICINITY THEREOF.
S1218
RETURN

FIG.17

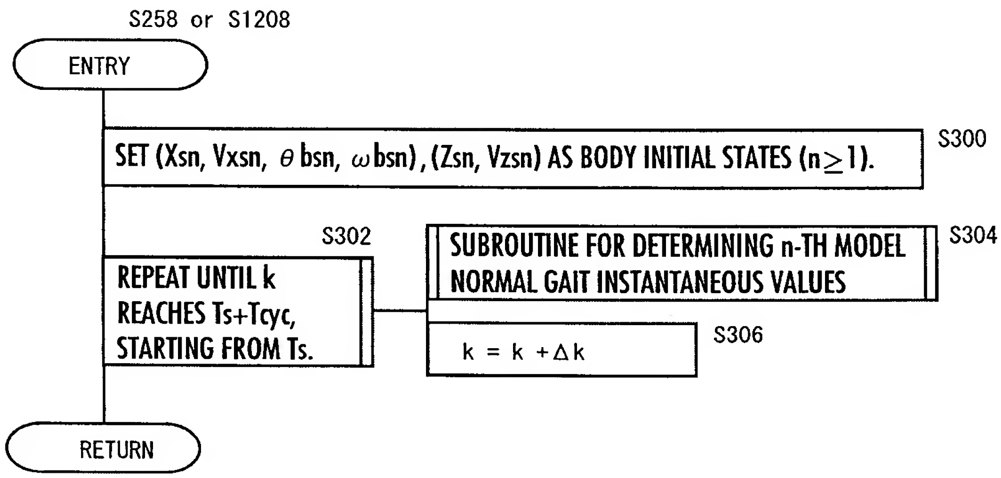

S258 or S1208
ENTRY
SET (Xsn, Vxsn, θbsn, ωbsn), (Zsn, Vzsn) AS BODY INITIAL STATES (n≥1).
S300
S302
REPEAT UNTIL k REACHES Ts+Tcyc, STARTING FROM Ts.
SUBROUTINE FOR DETERMINING n-TH MODEL NORMAL GAIT INSTANTANEOUS VALUES
S304
k = k +Δk
S306
RETURN

FIG.18

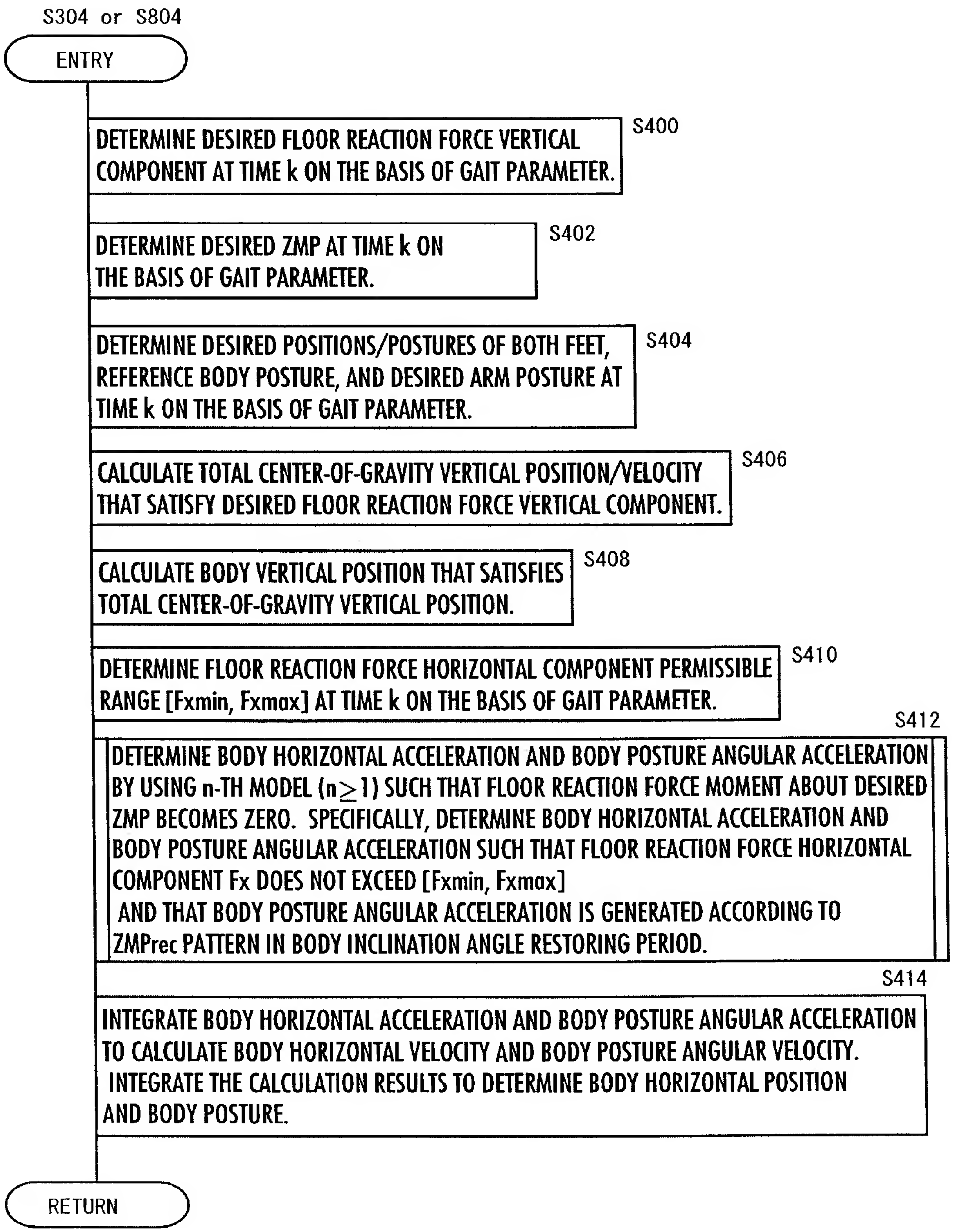

S304 or S804
ENTRY
S400
DETERMINE DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT AT TIME k ON THE BASIS OF GAIT PARAMETER.
S402
DETERMINE DESIRED ZMP AT TIME k ON THE BASIS OF GAIT PARAMETER.
S404
DETERMINE DESIRED POSITIONS/POSTURES OF BOTH FEET, REFERENCE BODY POSTURE, AND DESIRED ARM POSTURE AT TIME k ON THE BASIS OF GAIT PARAMETER.
S406
CALCULATE TOTAL CENTER-OF-GRAVITY VERTICAL POSITION/VELOCITY THAT SATISFY DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT.
S408
CALCULATE BODY VERTICAL POSITION THAT SATISFIES TOTAL CENTER-OF-GRAVITY VERTICAL POSITION.
S410
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE [Fxmin, Fxmax] AT TIME k ON THE BASIS OF GAIT PARAMETER.
S412
DETERMINE BODY HORIZONTAL ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION BY USING n-TH MODEL (n≥1) SUCH THAT FLOOR REACTION FORCE MOMENT ABOUT DESIRED ZMP BECOMES ZERO. SPECIFICALLY, DETERMINE BODY HORIZONTAL ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION SUCH THAT FLOOR REACTION FORCE HORIZONTAL COMPONENT Fx DOES NOT EXCEED [Fxmin, Fxmax] AND THAT BODY POSTURE ANGULAR ACCELERATION IS GENERATED ACCORDING TO ZMPrec PATTERN IN BODY INCLINATION ANGLE RESTORING PERIOD.
S414
INTEGRATE BODY HORIZONTAL ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION TO CALCULATE BODY HORIZONTAL VELOCITY AND BODY POSTURE ANGULAR VELOCITY. INTEGRATE THE CALCULATION RESULTS TO DETERMINE BODY HORIZONTAL POSITION AND BODY POSTURE.
RETURN

FIG.19

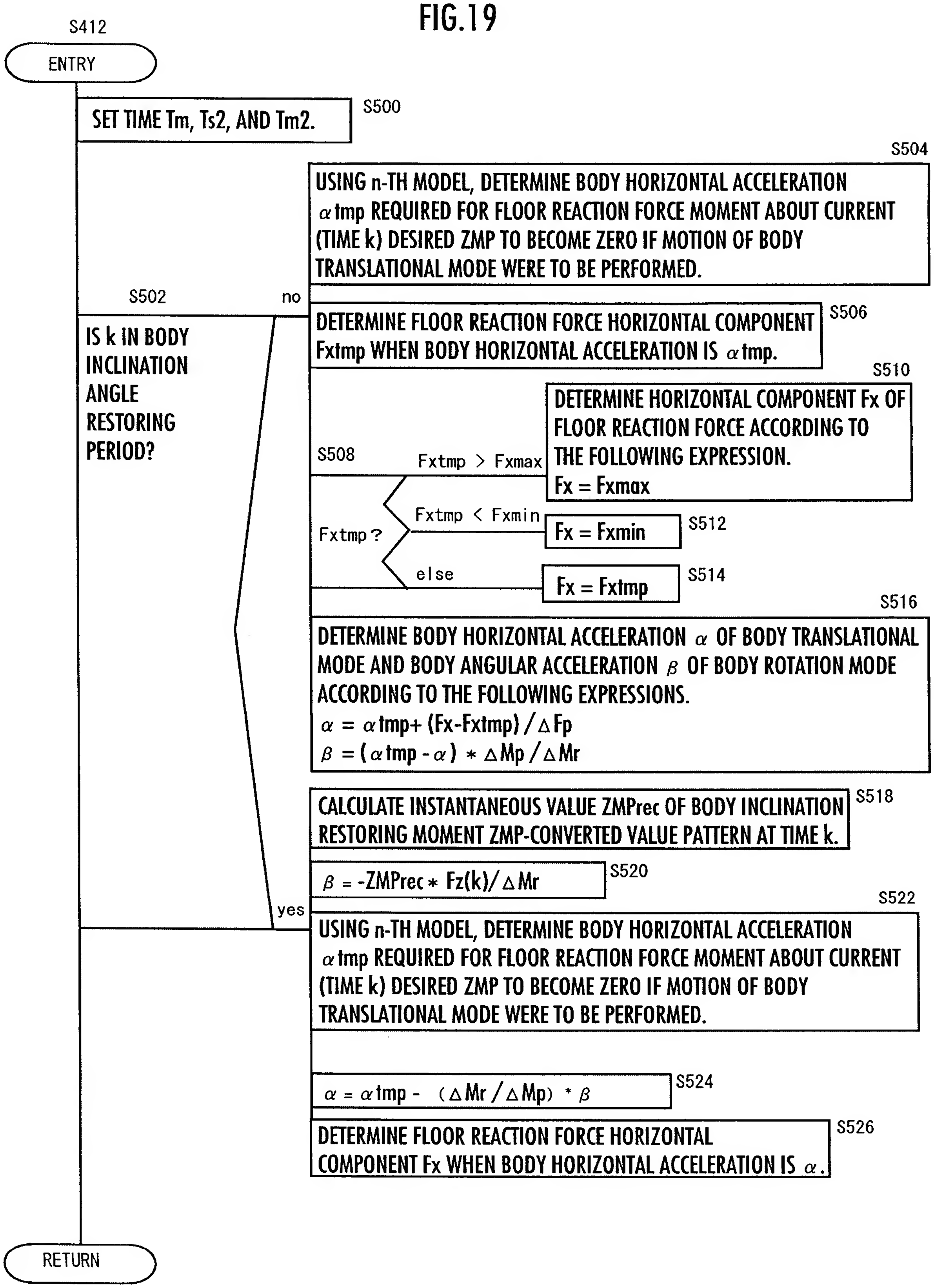

S412
ENTRY
SET TIME Tm, Ts2, AND Tm2.
S500
S502
IS k IN BODY INCLINATION ANGLE RESTORING PERIOD?
no
S504
USING n-TH MODEL, DETERMINE BODY HORIZONTAL ACCELERATION α tmp REQUIRED FOR FLOOR REACTION FORCE MOMENT ABOUT CURRENT (TIME k) DESIRED ZMP TO BECOME ZERO IF MOTION OF BODY TRANSLATIONAL MODE WERE TO BE PERFORMED.
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT Fxtmp WHEN BODY HORIZONTAL ACCELERATION IS α tmp.
S506
S508
Fxtmp ?
Fxtmp > Fxmax
S510
DETERMINE HORIZONTAL COMPONENT Fx OF FLOOR REACTION FORCE ACCORDING TO THE FOLLOWING EXPRESSION.
Fx = Fxmax
Fxtmp < Fxmin
Fx = Fxmin
S512
else
Fx = Fxtmp
S514
S516
DETERMINE BODY HORIZONTAL ACCELERATION α OF BODY TRANSLATIONAL MODE AND BODY ANGULAR ACCELERATION β OF BODY ROTATION MODE ACCORDING TO THE FOLLOWING EXPRESSIONS.
α = α tmp+ (Fx-Fxtmp) / ΔFp
β = (α tmp - α) * ΔMp / ΔMr
yes
CALCULATE INSTANTANEOUS VALUE ZMPrec OF BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PATTERN AT TIME k.
S518
β = -ZMPrec * Fz(k)/ ΔMr
S520
S522
USING n-TH MODEL, DETERMINE BODY HORIZONTAL ACCELERATION α tmp REQUIRED FOR FLOOR REACTION FORCE MOMENT ABOUT CURRENT (TIME k) DESIRED ZMP TO BECOME ZERO IF MOTION OF BODY TRANSLATIONAL MODE WERE TO BE PERFORMED.
α = α tmp - (ΔMr / ΔMp) * β
S524
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT Fx WHEN BODY HORIZONTAL ACCELERATION IS α.
S526
RETURN

FIG.20

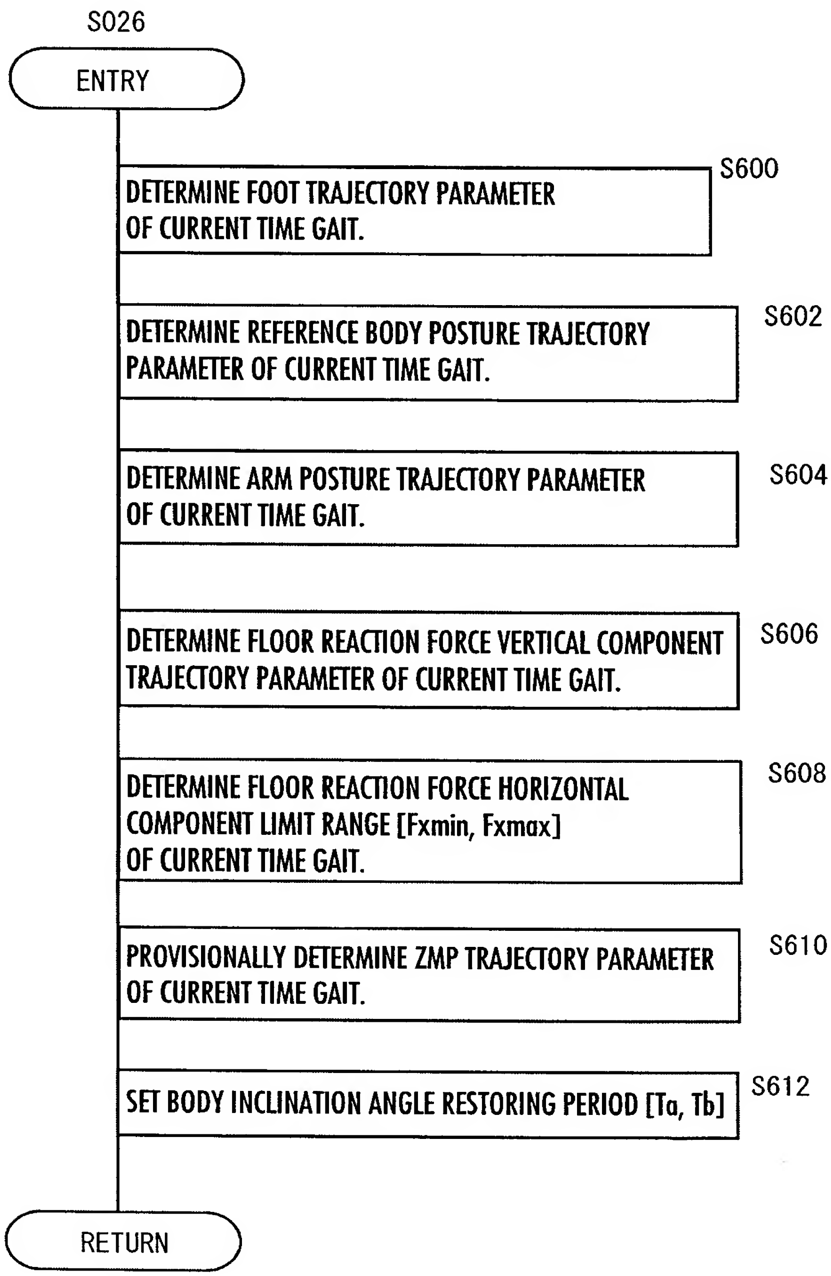

S026
ENTRY
S600
DETERMINE FOOT TRAJECTORY PARAMETER OF CURRENT TIME GAIT.
S602
DETERMINE REFERENCE BODY POSTURE TRAJECTORY PARAMETER OF CURRENT TIME GAIT.
S604
DETERMINE ARM POSTURE TRAJECTORY PARAMETER OF CURRENT TIME GAIT.
S606
DETERMINE FLOOR REACTION FORCE VERTICAL COMPONENT TRAJECTORY PARAMETER OF CURRENT TIME GAIT.
S608
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT LIMIT RANGE [Fxmin, Fxmax] OF CURRENT TIME GAIT.
S610
PROVISIONALLY DETERMINE ZMP TRAJECTORY PARAMETER OF CURRENT TIME GAIT.
S612
SET BODY INCLINATION ANGLE RESTORING PERIOD [Ta, Tb]
RETURN

FIG.21

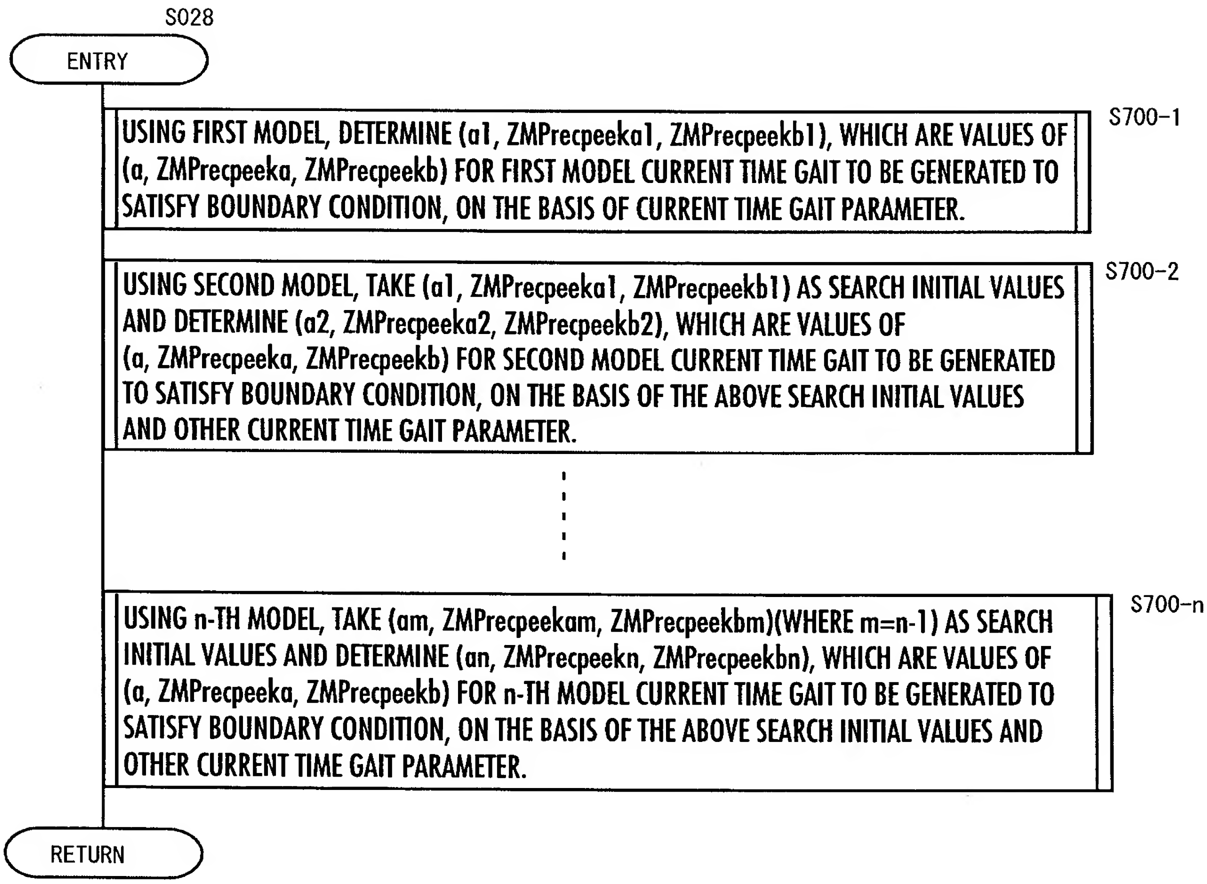
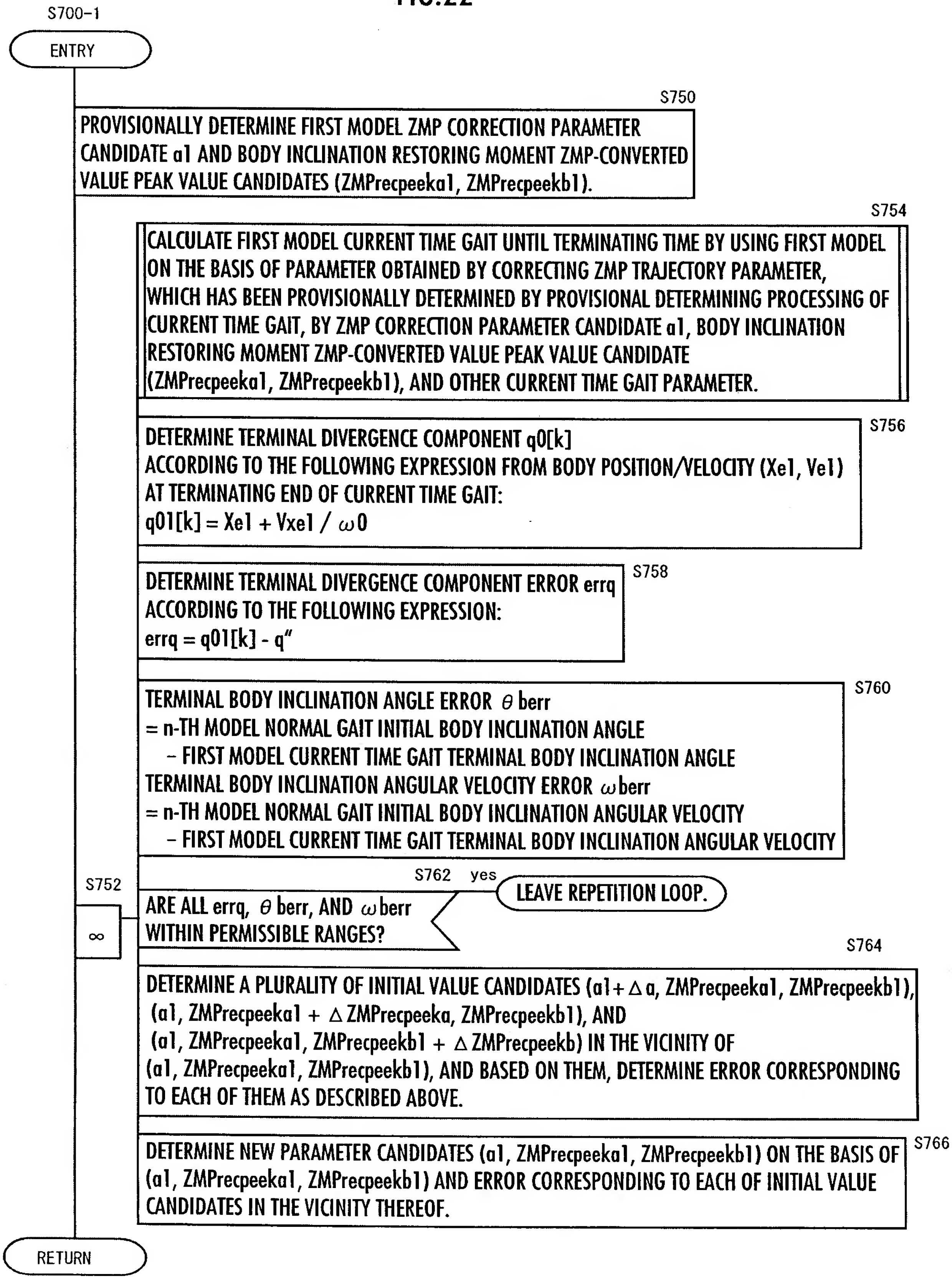

S028
ENTRY
USING FIRST MODEL, DETERMINE (a1, ZMPrecpeeka1, ZMPrecpeekb1), WHICH ARE VALUES OF (a, ZMPrecpeeka, ZMPrecpeekb) FOR FIRST MODEL CURRENT TIME GAIT TO BE GENERATED TO SATISFY BOUNDARY CONDITION, ON THE BASIS OF CURRENT TIME GAIT PARAMETER.
S700-1
USING SECOND MODEL, TAKE (a1, ZMPrecpeeka1, ZMPrecpeekb1) AS SEARCH INITIAL VALUES AND DETERMINE (a2, ZMPrecpeeka2, ZMPrecpeekb2), WHICH ARE VALUES OF (a, ZMPrecpeeka, ZMPrecpeekb) FOR SECOND MODEL CURRENT TIME GAIT TO BE GENERATED TO SATISFY BOUNDARY CONDITION, ON THE BASIS OF THE ABOVE SEARCH INITIAL VALUES AND OTHER CURRENT TIME GAIT PARAMETER.
S700-2
USING n-TH MODEL, TAKE (am, ZMPrecpeekam, ZMPrecpeekbm)(WHERE m=n-1) AS SEARCH INITIAL VALUES AND DETERMINE (an, ZMPrecpeekn, ZMPrecpeekbn), WHICH ARE VALUES OF (a, ZMPrecpeeka, ZMPrecpeekb) FOR n-TH MODEL CURRENT TIME GAIT TO BE GENERATED TO SATISFY BOUNDARY CONDITION, ON THE BASIS OF THE ABOVE SEARCH INITIAL VALUES AND OTHER CURRENT TIME GAIT PARAMETER.
S700-n
RETURN

FIG.22


S700-1
ENTRY
S750
PROVISIONALLY DETERMINE FIRST MODEL ZMP CORRECTION PARAMETER CANDIDATE a1 AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATES (ZMPrecpeeka1, ZMPrecpeekb1).
S754
CALCULATE FIRST MODEL CURRENT TIME GAIT UNTIL TERMINATING TIME BY USING FIRST MODEL ON THE BASIS OF PARAMETER OBTAINED BY CORRECTING ZMP TRAJECTORY PARAMETER, WHICH HAS BEEN PROVISIONALLY DETERMINED BY PROVISIONAL DETERMINING PROCESSING OF CURRENT TIME GAIT, BY ZMP CORRECTION PARAMETER CANDIDATE a1, BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATE (ZMPrecpeeka1, ZMPrecpeekb1), AND OTHER CURRENT TIME GAIT PARAMETER.
S756
DETERMINE TERMINAL DIVERGENCE COMPONENT q0[k]
ACCORDING TO THE FOLLOWING EXPRESSION FROM BODY POSITION/VELOCITY (Xe1, Ve1)
AT TERMINATING END OF CURRENT TIME GAIT:
q01[k] = Xe1 + Vxe1 / ω0
S758
DETERMINE TERMINAL DIVERGENCE COMPONENT ERROR errq
ACCORDING TO THE FOLLOWING EXPRESSION:
errq = q01[k] - q"
S760
TERMINAL BODY INCLINATION ANGLE ERROR θberr
= n-TH MODEL NORMAL GAIT INITIAL BODY INCLINATION ANGLE
- FIRST MODEL CURRENT TIME GAIT TERMINAL BODY INCLINATION ANGLE
TERMINAL BODY INCLINATION ANGULAR VELOCITY ERROR ωberr
= n-TH MODEL NORMAL GAIT INITIAL BODY INCLINATION ANGULAR VELOCITY
- FIRST MODEL CURRENT TIME GAIT TERMINAL BODY INCLINATION ANGULAR VELOCITY
S752
∞
S762
ARE ALL errq, θberr, AND ωberr WITHIN PERMISSIBLE RANGES?
yes
LEAVE REPETITION LOOP.
S764
DETERMINE A PLURALITY OF INITIAL VALUE CANDIDATES (a1+Δa, ZMPrecpeeka1, ZMPrecpeekb1), (a1, ZMPrecpeeka1 + ΔZMPrecpeeka, ZMPrecpeekb1), AND (a1, ZMPrecpeeka1, ZMPrecpeekb1 + ΔZMPrecpeekb) IN THE VICINITY OF (a1, ZMPrecpeeka1, ZMPrecpeekb1), AND BASED ON THEM, DETERMINE ERROR CORRESPONDING TO EACH OF THEM AS DESCRIBED ABOVE.
S766
DETERMINE NEW PARAMETER CANDIDATES (a1, ZMPrecpeeka1, ZMPrecpeekb1) ON THE BASIS OF (a1, ZMPrecpeeka1, ZMPrecpeekb1) AND ERROR CORRESPONDING TO EACH OF INITIAL VALUE CANDIDATES IN THE VICINITY THEREOF.
RETURN

# FIG.23

S700-n (n≧2)

ENTRY

S1700
SUBSTITUTE am AND (ZMPrecpeekam, ZMPrecpeekbm)(WHERE m=n-1) INTO n-TH MODEL ZMP CORRECTION PARAMETER CANDIDATE an AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATE (ZMPrecpeekan, ZMPrecpeekbn), RESPECTIVELY.

S1702
∞

S1704
CALCULATE n-TH MODEL CURRENT TIME GAIT UNTIL TERMINATING TIME BY USING n-TH MODEL ON THE BASIS OF PARAMETER OBTAINED BY CORRECTING ZMP PARAMETER, WHICH HAS BEEN PROVISIONALLY DETERMINED BY PROVISIONAL DETERMINING PROCESSING OF CURRENT TIME GAIT, BY ZMP CORRECTION PARAMETER CANDIDATE an, BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATE (ZMPrecpeekan, ZMPrecpeekbn), AND OTHER CURRENT TIME GAIT PARAMETER.

S1706
DETERMINE TERMINAL DIVERGENCE COMPONENT q0[k]
FROM BODY HORIZONTAL POSITION/VELOCITY (Xen, Ven)
AT TERMINATING END OF CURRENT TIME GAIT ACCORDING TO THE FOLLOWING EXPRESSION:
$q0n[k] = Xen + Vxen / \omega 0$

S1708
DETERMINE TERMINAL DIVERGENCE COMPONENT ERROR errq
ACCORDING TO THE FOLLOWING EXPRESSION:
$errq = q0n[k] - q''$

S1710
TERMINAL BODY INCLINATION ANGLE ERROR $\theta$berr
= n-TH MODEL NORMAL GAIT INITIAL BODY INCLINATION ANGLE
− n-TH MODEL CURRENT TIME GAIT INITIAL BODY INCLINATION ANGLE
TERMINAL BODY INCLINATION ANGULAR VELOCITY ERROR $\omega$berr
= n-TH MODEL NORMAL GAIT INITIAL BODY INCLINATION ANGULAR VELOCITY
− n-TH MODEL CURRENT TIME GAIT INITIAL BODY INCLINATION ANGULAR VELOCITY

S1712
ARE ALL errq, $\theta$berr, AND $\omega$berr WITHIN PERMISSIBLE RANGES?
yes → LEAVE REPETITION LOOP.

S1714
DETERMINE A PLURALITY OF INITIAL VALUE CANDIDATES (an+$\Delta$a, ZMPrecpeekan, ZMPrecpeekbn), (an, ZMPrecpeekan + $\Delta$ZMPrecpeeka, ZMPrecpeekbn), AND (an, ZMPrecpeekan, ZMPrecpeekbn + $\Delta$ZMPrecpeekb) IN THE VICINITY OF (an, ZMPrecpeekan, ZMPrecpeekbn), AND BASED ON THEM, DETERMINE ERROR CORRESPONDING TO EACH OF THEM AS DESCRIBED ABOVE.

S1716
DETERMINE NEW PARAMETER CANDIDATES (an, ZMPrecpeekan, ZMPrecpeekbn) ON THE BASIS OF (an, ZMPrecpeekan, ZMPrecpeekbn) AND ERROR CORRESPONDING TO EACH OF INITIAL VALUE CANDIDATES IN THE VICINITY THEREOF.

RETURN

FIG.24

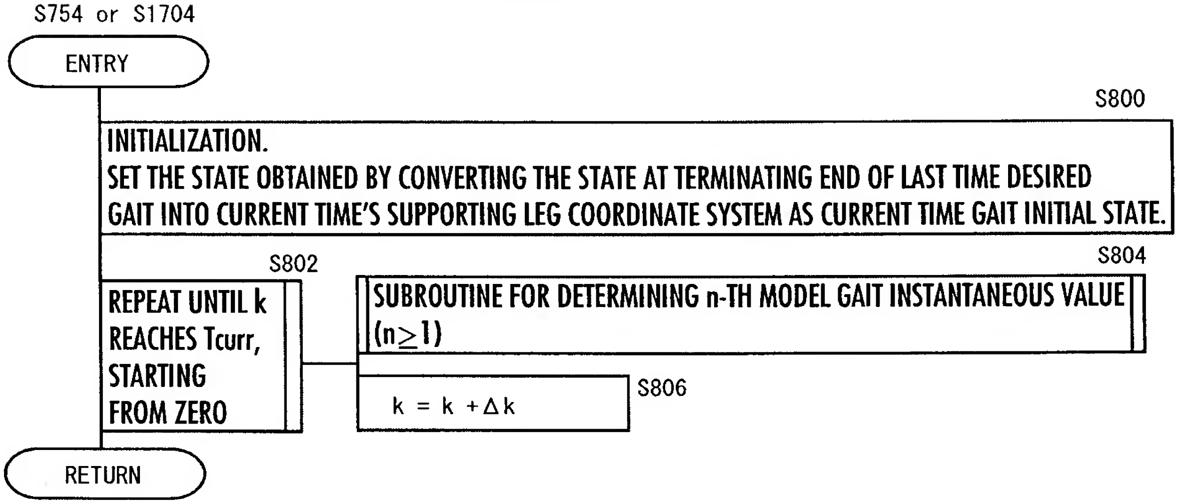



FIG.25

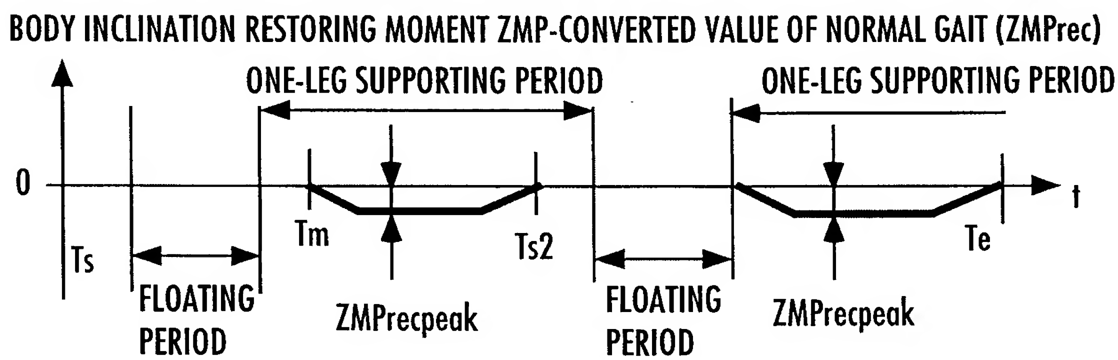



FIG.26

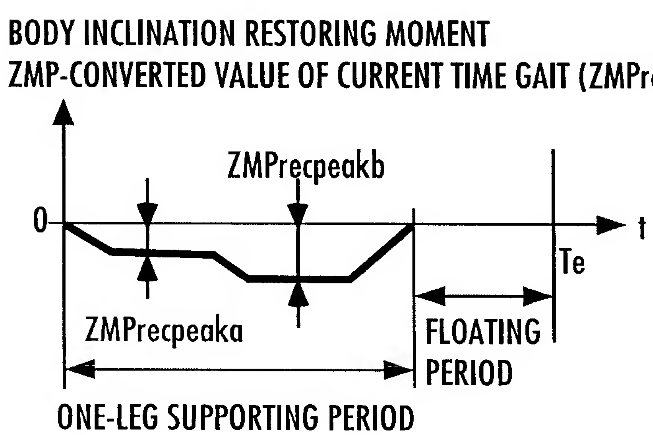


FIG.27

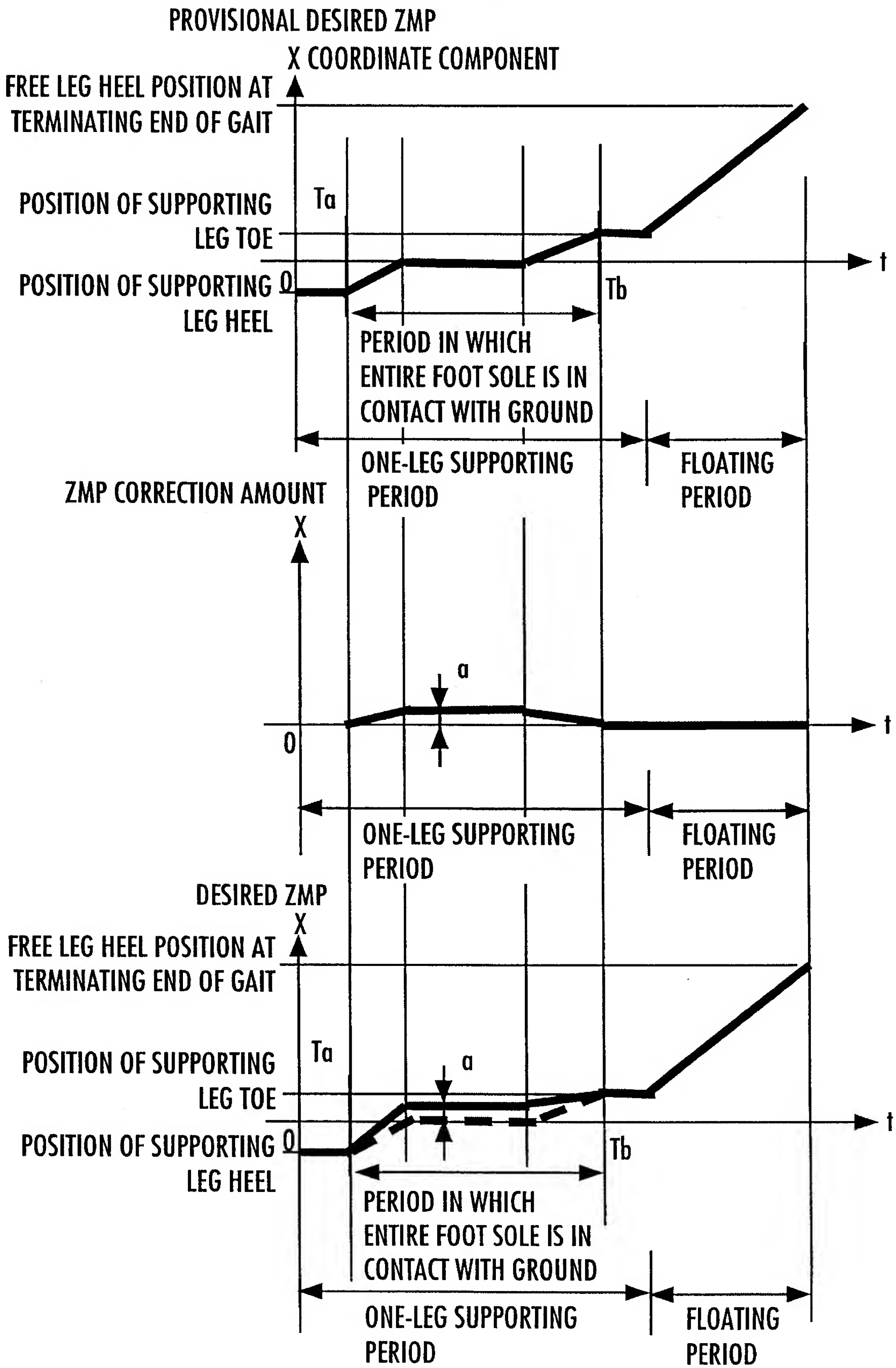

PROVISIONAL DESIRED ZMP
X COORDINATE COMPONENT
FREE LEG HEEL POSITION AT TERMINATING END OF GAIT
Ta
POSITION OF SUPPORTING LEG TOE
t
POSITION OF SUPPORTING LEG HEEL
0
Tb
PERIOD IN WHICH ENTIRE FOOT SOLE IS IN CONTACT WITH GROUND
ONE-LEG SUPPORTING PERIOD
FLOATING PERIOD
ZMP CORRECTION AMOUNT
X
a
0
t
ONE-LEG SUPPORTING PERIOD
FLOATING PERIOD
DESIRED ZMP
X
FREE LEG HEEL POSITION AT TERMINATING END OF GAIT
Ta
a
POSITION OF SUPPORTING LEG TOE
t
POSITION OF SUPPORTING LEG HEEL
0
Tb
PERIOD IN WHICH ENTIRE FOOT SOLE IS IN CONTACT WITH GROUND
ONE-LEG SUPPORTING PERIOD
FLOATING PERIOD

FIG.28

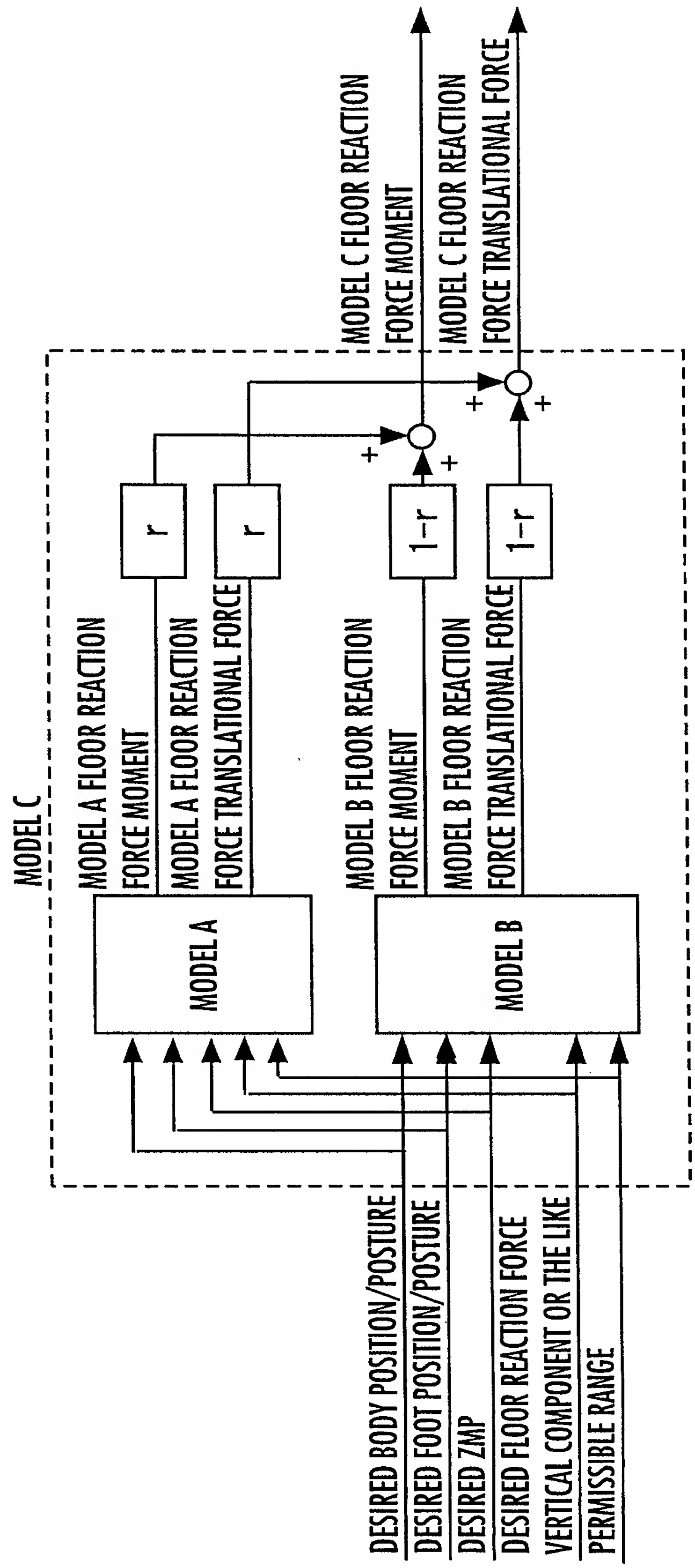
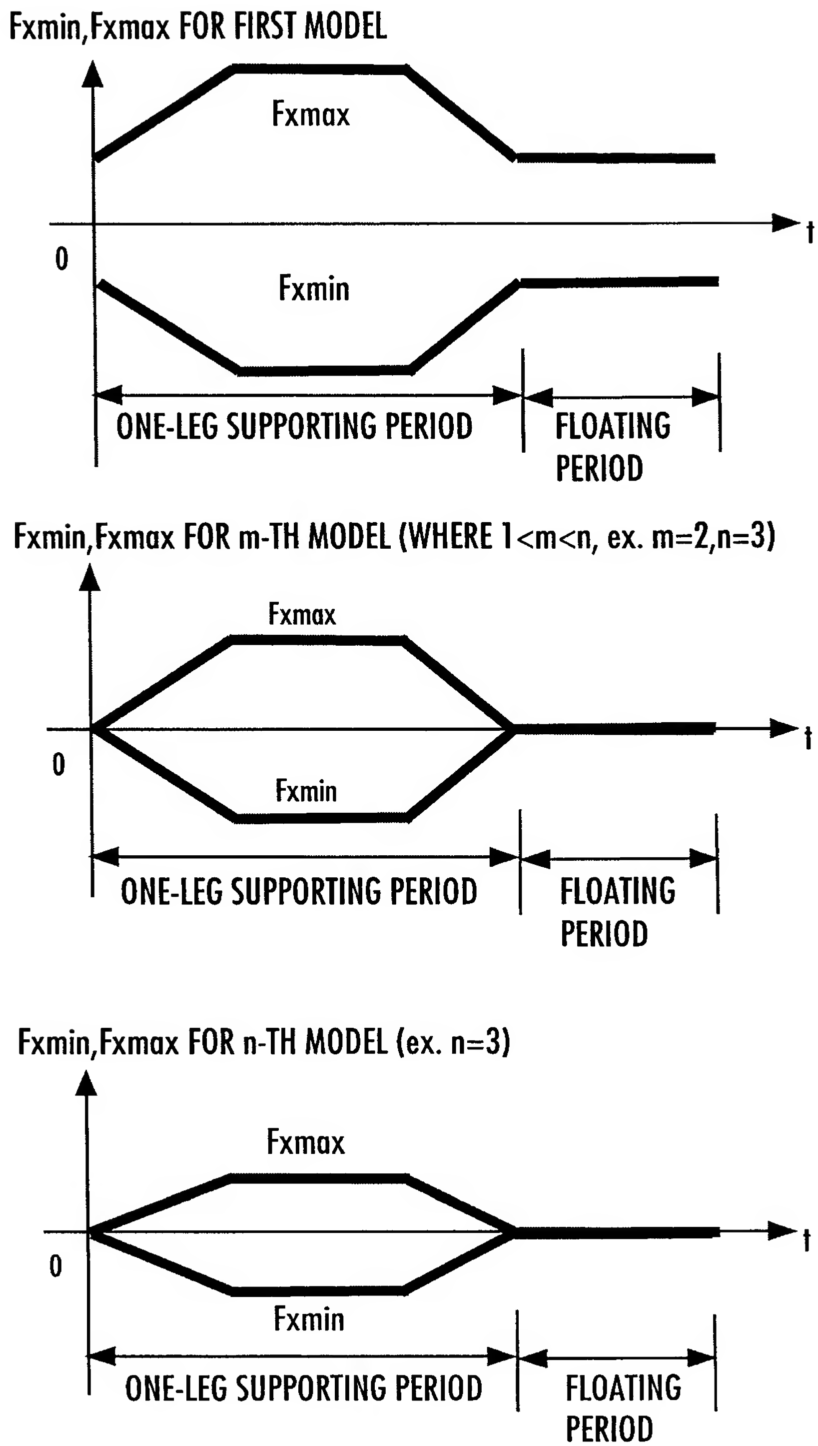

MODEL C
MODEL A
MODEL B
MODEL A FLOOR REACTION FORCE MOMENT
MODEL A FLOOR REACTION FORCE TRANSLATIONAL FORCE
MODEL B FLOOR REACTION FORCE MOMENT
MODEL B FLOOR REACTION FORCE TRANSLATIONAL FORCE
r
r
1−r
1−r
+
+
+
+
MODEL C FLOOR REACTION FORCE MOMENT
MODEL C FLOOR REACTION FORCE TRANSLATIONAL FORCE
DESIRED BODY POSITION/POSTURE
DESIRED FOOT POSITION/POSTURE
DESIRED ZMP
DESIRED FLOOR REACTION FORCE
VERTICAL COMPONENT OR THE LIKE
PERMISSIBLE RANGE

FIG.29


Fxmin,Fxmax FOR FIRST MODEL
Fxmax
t
0
Fxmin
ONE-LEG SUPPORTING PERIOD
FLOATING PERIOD
Fxmin,Fxmax FOR m-TH MODEL (WHERE 1<m<n, ex. m=2,n=3)
Fxmax
t
0
Fxmin
ONE-LEG SUPPORTING PERIOD
FLOATING PERIOD
Fxmin,Fxmax FOR n-TH MODEL (ex. n=3)
Fxmax
t
0
Fxmin
ONE-LEG SUPPORTING PERIOD
FLOATING PERIOD